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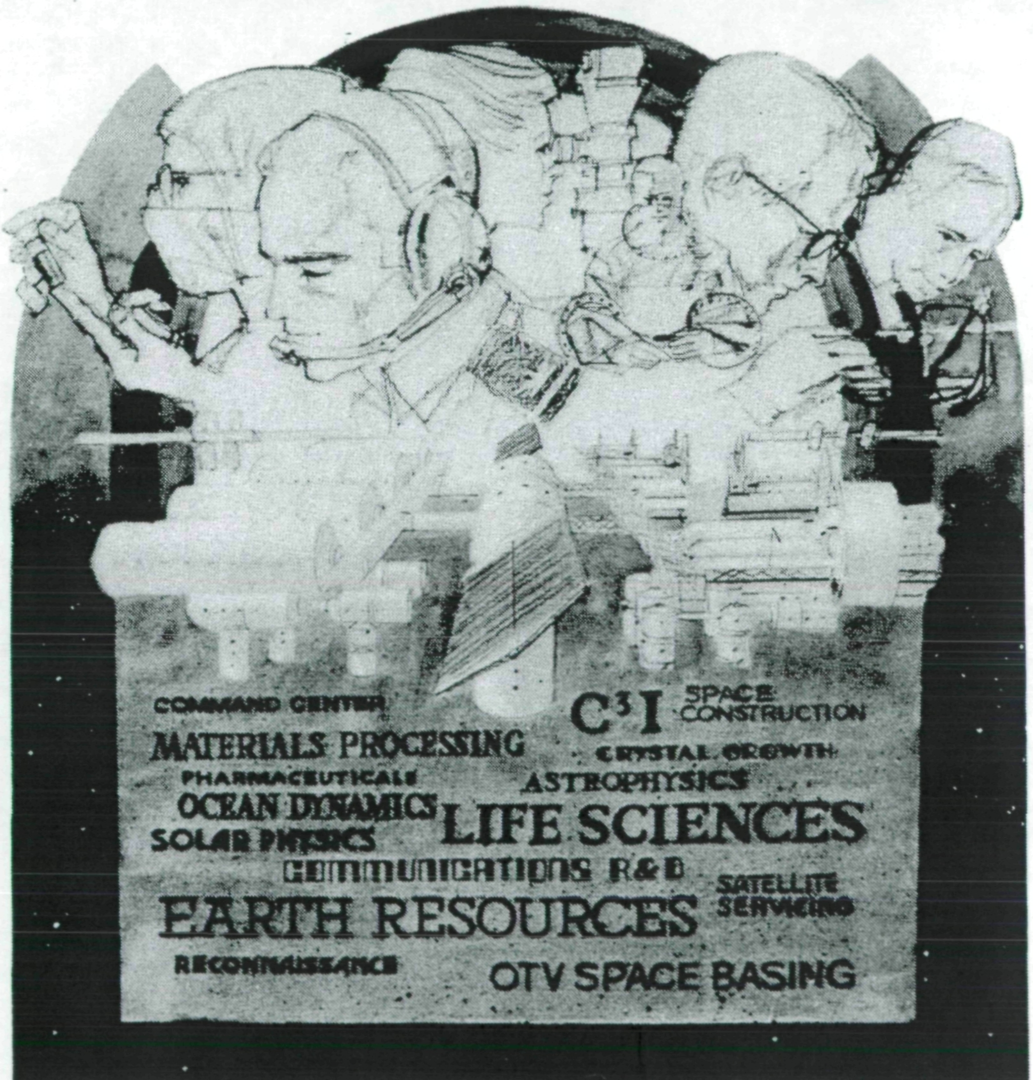
REPORT NO. GDC-ASP-83-004
CONTRACT NASW-3682

A STUDY OF SPACE STATION NEEDS, ATTRIBUTES & ARCHITECTURAL OPTIONS

FINAL REPORT

VOLUME II • TECHNICAL

BOOK 3 • ECONOMIC BENEFITS, COSTS, AND PROGRAMMATICS



GENERAL DYNAMICS
Convair Division

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FINAL REPORT
VOLUME II • TECHNICAL
BOOK 3 • ECONOMIC BENEFITS, COSTS, AND PROGRAMMATICS

22 April 1983

Submitted to
National Aeronautics and Space Administration
Washington, D.C. 20546

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A STUDY OF SPACE STATION NEEDS, ATTRIBUTES AND ARCHITECTURAL OPTIONS

FINAL REPORT

VOLUME I	Executive Summary
VOLUME II	Technical Report
Book 1	Mission Requirements
Appendix I	Mission Requirements Data Base
Appendix II	Space Station User Brochure and Fact Sheet
Book 2	Mission Implementation Options
Book 3	Economic Benefits, Costs and Programmatics
Appendix I	Space Station Prospectus
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PREFACE

The U.S. progress towards a complete space transportation system (STS) for the exploration and exploitation of space achieved an important milestone when the Space Shuttle became operational. Other elements of the system, such as the Payload Assist Modules, Inertial Upper Stage, Spacelab, Extra Vehicular Maneuvering System, and the Shuttle-Centaur Upper Stage are either in use or under development. However, there are other important STS elements that still require definition and development - the major new element being a manned Space Station in low earth orbit. When available, a manned Space Station, plus the elements listed above, will provide the capability for a permanent manned presence in space.

The availability of a manned Space Station will:

a. Provide a versatile space system for an active space science program.

b. Stimulate developmnt of advanced technologies.

c. Provide continuity to the civilian space program.

d. Stimulate commercial activities in space.

e. Enhance national security.

Through these, U.S. leadership in space will be maintained and our image abroad will be enhanced. The Space Station will provide:

a. A permanent manned presence.

b. Improved upper stage operations.

c. Maintenance of space systems through on-orbit checkout and repair.

d. Assembly and construction of large space elements.

It will also enhance Space Shuttle utilization as a transportation vehicle by releasing it from sortie missions that currently substitute for Space Station missions.

The Space Station will be a facility having the following general characteristics:

a. Support manned and unmanned elements.

b. User friendly.

c. Evolutionary in nature for size, capability, and technology.

d. High level of autonomous operations.

e. Shuttle compatible.

The primary purpose of this study was to further identify, collect, and analyze the science, applications, commercial, technology, U.S. national security, and space operations missions that require or that will be materially benefited by the availability of a permanent manned Space Station and to identify and characterize the Space Station attributes and capabilities that will be necessary to satisfy those mission requirements.

NASA intends to integrate these data, recommendations, and insights developed under this contracted effort with those developed from in-house activities and other sources and then synthesize from this information a set of mission objectives and corresponding Space Station requirements that will be used in future phases of study and Space Station definition.

The study objectives as defined in the Request for Proposal (RFP) are:

a. Identify, collect, and analyze missions that require, or will materially benefit from, the availability of a Space Station:

- Science
- Applications
- Commercial
- Technology
- Space operations
- U.S. national security

b. Identify and characterize the Space Station attributes and capabilities that are necessary to meet these requirements.

c. Recommend mission implementation approaches and architectural options.

d. Recommend time phasing of implementation concepts.

e. Define the rough order of magnitude programmatic/cost implications.

Book 1 will address the first objective and provide the realistic, time-phased set of mission requirements upon which the balance of the study was based. Accomplishments of objectives b, c, and d are documented in Book 2, and objective e is addressed in Book 3. Book 4 contains a definition and an analysis of national security missions (classified).

FOREWORD

This final report was prepared by General Dynamics Convair Division for NASA Headquarters under Contract Number NASW-3682.

The study was conducted from 20 August 1982 through 22 April 1983. A midterm briefing was presented at NASA Headquarters on 17 November 1982; a final briefing was presented on 5 April 1983, also at NASA Headquarters.

The study was conducted within the Space Programs Organization at General Dynamics Convair Division, headed by W.F. Rector, III, Space Vice President and Program Director. D.E. Charhut, Director of Advanced Space Programs, was assigned specific responsibility for the study. The NASA COR is Brian Pritchard of the Space Station Task Force headed by John Hodge.

General Dynamics Convair Division personnel who significantly contributed to the study include:

Study Manager	Otto Steinbronn
Mission Requirements	Warren Hardy - Manager Jim Peterson Charlie Hyde
Mission Implementation	John Bodle - Manager Earl Davis Tom Kessler Norm Gray
Economic Benefits, Costs and Programmatics	Bob Bradley - Manager Michael Simon Sam Wagner
Nation Security Missions	Al Phillips Clint James

Subcontract support was obtained from Space Communications Co. (SPACECOM) in the area of communication spacecraft and related technologies, and from Advanced Technology, Inc. in the area of life science and life support systems.

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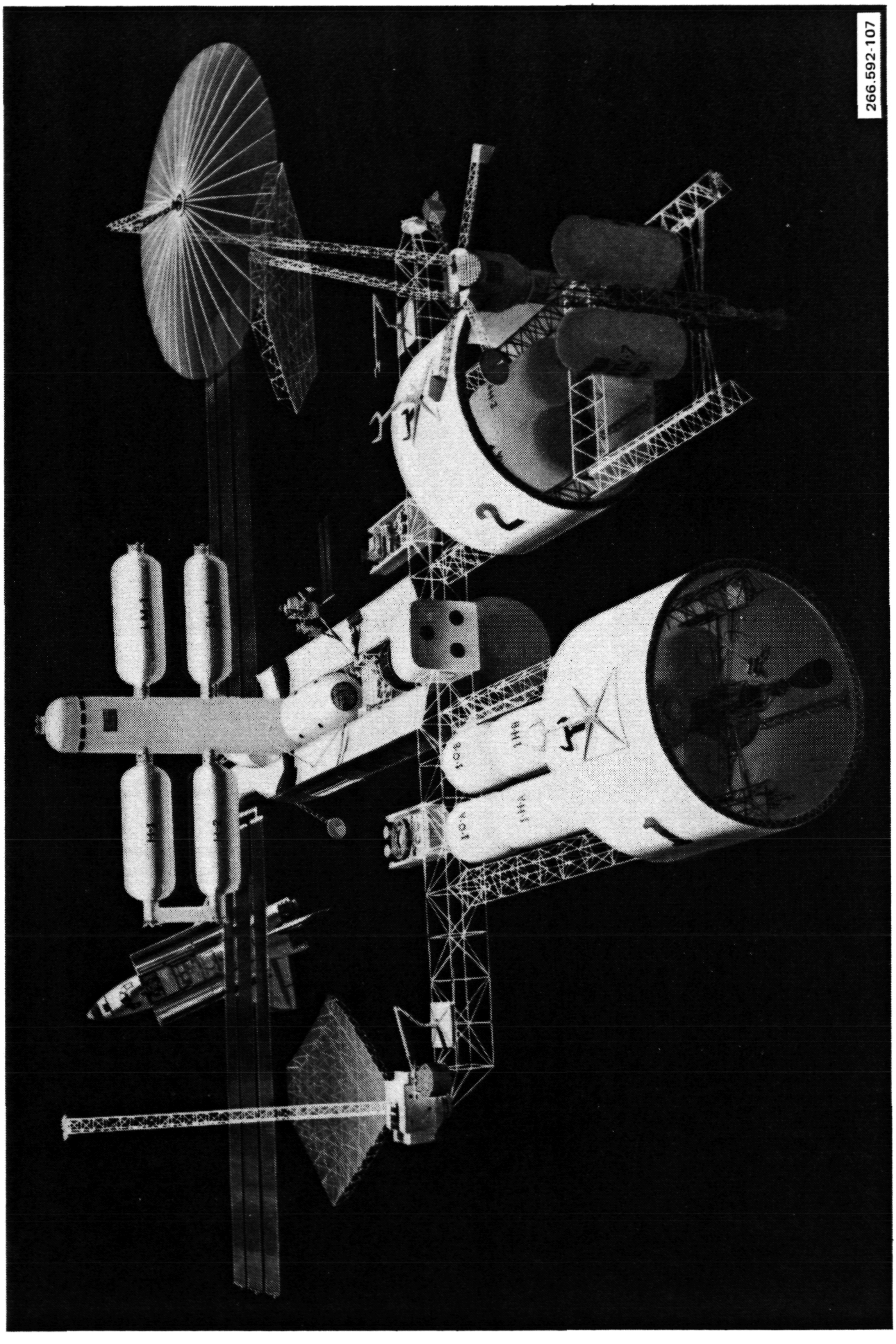
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SECTION 1

INTRODUCTION AND SUMMARY

Space Station Economic Benefits, Costs and Programmatics is the third volume of General Dynamics Convair (GDC) Division's Study of Space Station Needs, Attributes and Architectural Options, and documents Task 3.3 of the study. The principal tasks addressed during this study are summarized in Table 1-1. The title of this volume was carefully selected, and reflects the emphasis of this study on the economic benefits of the Space Station.

Section 2, "Economic Benefits," provides an in-depth analysis of the economic value of the Space Station. Of particular interest is the space-based orbital transfer vehicle (OTV), which distinguishes itself as the most economically attractive of all the Space Station functions. It should be emphasized, however, that other Space Station activities, most notably materials processing in space (MPS), have substantial economic potential, although their future benefits are currently very difficult to credibly quantify and are not included in the economic benefits profile. The economic benefit estimates of this study, projected at nearly $1.7 billion per year by the mid-1990s, must be considered conservative if for no other reason than because they do not include any significant benefits from MPS.

Table 1-1. Task Objectives and Approach

Economic benefits
- Parametric analysis of significant cost elements of alternative approaches & identify cost drivers & sensitivities
  - Research & production
  - Space-based OTV
  - Satellite servicing

Programmatic comparisons
- Generate alternate program costs with a parametric cost model (element level) & a phased funding model
  - Mission payload costs
  - Architectural options
  - Evolutionary options

Business opportunity assessment
- Examine alternate approaches to industry involvement for financing, developing, marketing & operating space station resources
  - Business assessment (Space Station Propectus)
  - Government/industry options (i.e., SDC)

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Section 3 of this volume, "Program Costs," provides estimates of Space Station development and production costs, and also of the costs of the candidate missions that have been identified during this study. Since this was not a design study, these cost projections are presented in limited detail. The key cost relationships among major Space Station systems, elements and missions, however, are readily evident. The total cost of establishing the Space Station functions discussed in Section 2, at $6-10 billion, are consistent with the estimates of previous studies. The benefits data of the Section 2 are integrated into the Section 3 in cash-flow analyses, which show a payback period of 10 to 15 years from the initiation of Space Station operations.

The fourth and final section, "Programmatics," discusses the basic criteria used in the evaluation of the economic benefits of a Space Station program. Emphasis is given to private industry investment considerations and their relevance to the Space Station. A major objective of this study was to identify the requirements for private-sector participation in a Space Station enterprise, and the Section 4 focuses on this issue as it explores the different ways in which the government can structure a Space Station program to encourage private investment. Several different government-industry partnership options are developed and evaluated, with the suggested organization of a Space Development Corporation to combine the most favorable aspects of each of these programmatic alternatives.

As a supplement to this study, GDC has provided (Appendix I) a Space Station Prospectus to show how an alternative Space Station program, based on private-sector initiative, might be established. The prospectus is a fictitious stock offering for Consolidated Space Enterprises (a fictitious company), which would organize and retain partnership in 10 subsidiary Space Station companies, each of which would develop a particular Space Staton capability. Interested readers of this volume are encouraged to obtain copies of the prospectus from the Advanced Space Programs Office of General Dynamics Convair Division. It is hoped that this study volume and the Space Station Prospectus will enhance government and industry capabilities for developing the economic potential of the Space Station.

The principal contributers to this volume were: M.C. Simon - Economic Benefits (Section 2) and Programmatic and Business Opportunity Assessment (Section 4); and S.L. Wagner and R.E. Bradley - Program Cost Estimates (Section 3).

SECTION 2

ECONOMIC BENEFITS

2.1 INTRODUCTION

A detailed economic benefits analysis (see Figure 2-1) was performed for the three Space Station functions studied: the space-based orbital transfer vehicle (OTV), satellite servicing, and research and production. Midterm conclusions gave a preliminary indication that the OTV function would provide the greatest economic benefit, and analyses conducted during the second half of the study supported these findings, as shown in Figure 2-2. Final results also supported the initial conclusion that national security, commercial communications, and commercial materials processing in space users would derive the greatest economic benefit from the Space Station.

The principal findings of the economic benefits analysis documented in this volume are summarized in Table 2-1 and Figure 2-3.

2.2 SPACE-BASED OTV

2.2.1 OVERVIEW OF OTV BENEFITS. The space-based orbital transfer vehicle (OTV) represents one of the most economically attractive functions of a manned Space Station. The primary purpose of the OTV will be to deliver payloads from low earth-orbit (LEO) to geosynchronous orbit (GEO) and other high energy orbits beyond the range of the Space Shuttle. Payloads will first be delivered to the Space Station via Shuttle, and then processed at the Space Station for boost to higher orbit on the next scheduled OTV mission. The traffic model defined by this study indicates that OTV missions would probably be carried out an average of once or twice per month.

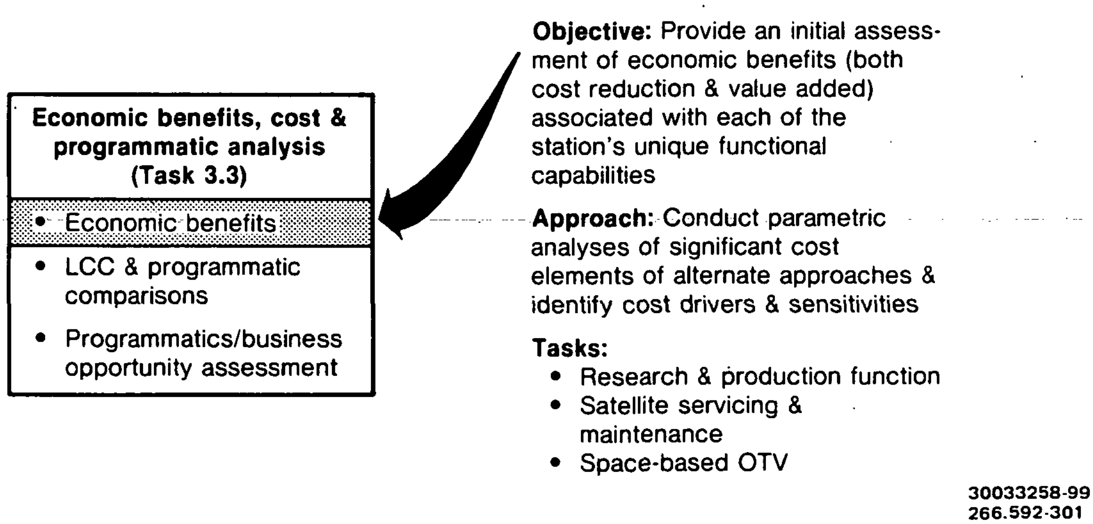

Figure 2-1. Economic Benefits Studies

Space Station Capability

	Space-based OTV	LEO servicing	Man-operated function	GEO servicing	Co-orbiting free-flyers	Satellite logistical support/resupply	On-orbit assembly	Data processing/communications	
National security	●	●		○		○	○	○	10
Commercial communications	●		○	●		○	○		9
Commercial materials processing in space		○	●		●	○			8
Astrophysics	○	●			○	○		○	7
Technology development	○	○	○	○			○	○	6
Life sciences			●						3
Commercial Earth & oceans observations	○	○							2
Earth & planetary observations	○	○							2
Environmental observations	○	○							2
	11	11	8	5	4	4	3	3	

● Significant benefit (3 pts) ○ Moderate benefit (1 pt) ☐ Minor or no benefit (0 pts)

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Figure 2-2. Economic Benefits Overview

Table 2-1. Economic Benefits Summary

Research & Production

- Near-term benefits to commercial, science & applications users
- Long-term benefits in materials processing & space industrialization

Space-based OTV

- Significant reduction in cost to GEO
- Benefits to shuttle users
- "ET tanker" concept

Satellite servicing

- Developed servicing benefits model in conjunction with GSFC
- 80% reduction in TMS servicing costs

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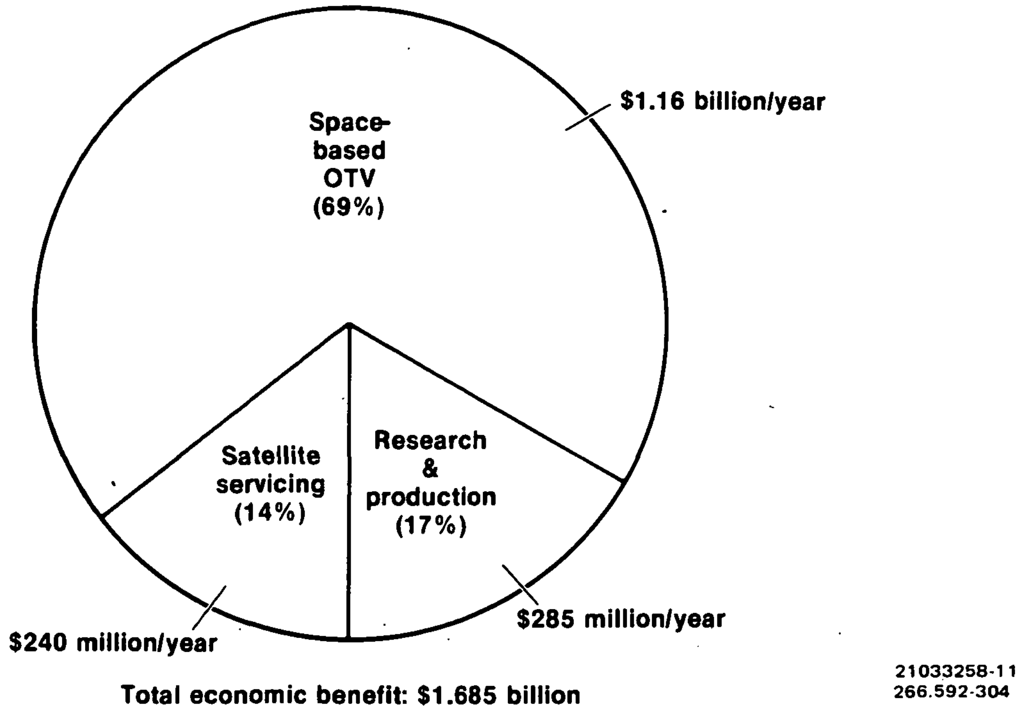

Figure 2-3. Space Station Economic Benefits (1984 $)

The economic viability of the OTV will depend primarily on three major factors. These are:

a. Reusability of the vehicles

b. Efficiency in propellant delivery to LEO

c. Reduction in Shuttle charge factors for payload delivery to LEO

2.2.1.1 Reusability. As a reusable upper stage, the space-based OTV will have a distinct economic advantage over all other expendable boosters. The total hardware and operations cost of an OTV mission, excluding propellant costs, is estimated at about $4 million, the majority of which is related to flight operations and OTV maintenance costs. The OTV production costs and the cost of initial delivery of the space vehicle to LEO will be amortized over as many as 240 flights and will represent a relatively small fraction of the cost of a typical OTV mission.

Table 2-2 summarizes OTV missions costs, based on the following ground rules and assumptions: 1) spare parts and refurbished OTV engines are delivered via Shuttle to LEO in a special OTV resupply module for every 20 OTV missions, at a total cost of $15 million, or $750,000 per OTV mission; 2) refurbishment of the OTV advanced space engine is included in this total; 3) Manpower costs per mission of $1.2 million include 2000 hours of ground support (at $100/hour) and 200 hours of Space Station crew time (at $10,000/hour).

Table 2-2. OTV Mission Cost (Excluding Propellant Costs) (1984 $M)

Unit		
OTV Unit Cost	$120 M	
OTV Delivery Cost to LEO	$120 M	
Unit Subtotal	$240 M	
÷ 240 Flights (OTV Lifetime) = Amortized Cost/Flight		($1.00 M)
Spares		
Engine: Refurbished every 20 flights at $2 million; cost/flight		$0.10 M
Avionics: $1 million for 20 flights		$0.05 M
RCS: $1 million for 20 flights		$0.05 M
Miscellaneous: $1 million for 20 flights		$0.05 M
Transportation of Spares: $10 million for 20 flights; cost/flight		$0.50 M
Spares Subtotal: $15 million for 20 flights; cost/flight		($0.75 M)
Manpower		
Ground Support: 2000 hours at $100/hour		$0.20 M
Space Station Crew Time: 200 hours at $10,000/hour		$2.00 M
Manpower Subtotal		($2.20 M)
Total Cost Per OTV Flight (Excluding Propellants)		$3.95 M

Since the OTV would have a payload capacity of 11,000 pounds to GEO, $4 million would represent a large cost advantage over the alternative means of attaining a similar launch capability with expendable vehicles. Table 2-3 compares the reusable OTV mission cost with the hardware costs of several expendable upper stages. Total mission costs of these systems (including STS and related costs) are shown graphically in Figure 2-4.

The OTV mission cost as described so far, however, represents only part of the total cost of an OTV mission, just as the upper-stage hardware costs in Table 2-3 are not the total costs that users of those vehicles must assume. The total cost of a PAM-D mission, for example, would be much higher than the $6 million indicated, with the inclusion of Shuttle and payload integration costs. The total cost of an OTV mission would exceed the $4 million in hardware and operations costs, due primarily to the cost of delivering OTV propellant to LEO. If OTV propellants are shipped to the Space Station via conventional means in the Space Shuttle cargo bay, then the total cost of an OTV mission rises by about $40 million, diminishing the economic benefit of the space-based system. Hence, efficiency in propellant delivery to LEO will be an important factor in developing a cost-effective space-based OTV.

Table 2-3. Upper-Stage Cost Comparison (Hardware Only) (1984$)

	P/L Capacity to GEO	Cost Per Vehicle ($M)	Cost Per Pound to GEO
PAM-D	1,300	$ 6	$ 4,615
PAM-D II	1,600	9	5,625
PAM-A	2,000	8	4,000
IUS	5,000	60	12,000
IUS First Stage	6,700	22	3,284
Shuttle-Centaur	14,000	40	2,857
Space-Based OTV	11,000	4	364

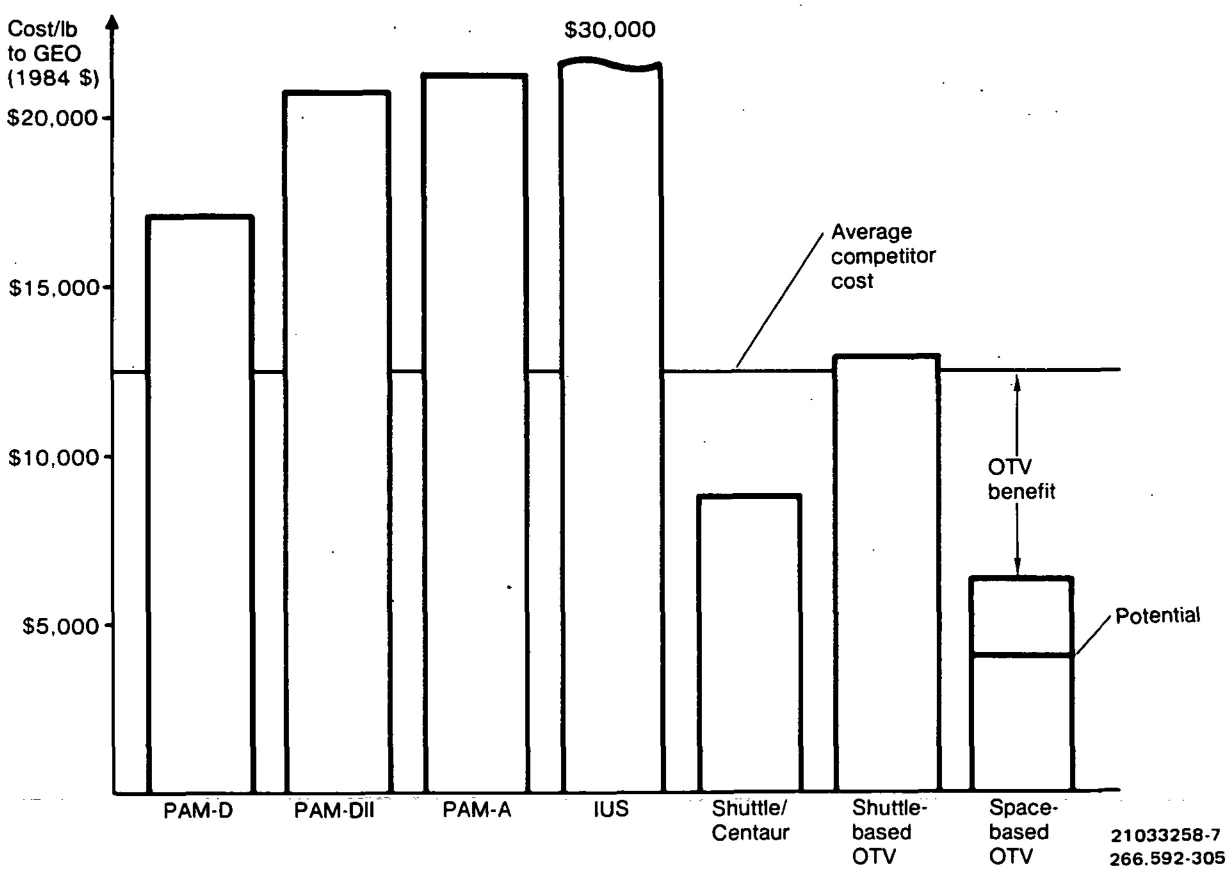

Figure 2-4. Upper-Stage Transportation Cost (1984 $/LB to GEO)

2.2.1.2 Efficiency in Propellant Delivery. Several possibilities exist for low-cost propellant delivery to LEO. From an OTV economics standpoint, the ideal solution would be to make use of the residual propellant that remains in the Shuttle external fuel tank (ET) after the Orbiter has achieved orbital velocity and its main engines are cut off. Although some cost would be involved in the recovery of the propellant and its subsequent transportation

to the Space Station, delivery of the fuel from Earth to LEO would be essentially free. This propellant could then be purchased from NASA by an OTV Operating Authority at a price that would cover the cost of the recovery operation, plus yield a profit that could then benefit the STS users.

Based on an overall judgment of the OTV operating scenario, it appears that a purchase price of $500 per pound of net propellant recovered would be appropriate. With an average net recovery of 11,600 pounds of propellant per Shuttle mission, NASA could generate up to $5.8 million in revenue, depending on the cost of the recovery operation. Since fight operations and refurbishing costs for the propellant recovery missions would probably be very small as compared with the $4 million cost of high-orbit payload delivery flights, NASA's income from the sale of recovered propellant would in all likelihood be fairly close to the $5.8 million per Shuttle flight figure.

The Honeybee propellant recovery scenario described in Volume II would be an ideal solution if not for two major drawbacks. First, there are significant technological uncertainties involved in executing rapid rendezvous operations with the Shuttle and extracting propellant during the critical moments following Shuttle main engine cut-off. Second, the amount of propellant that can be recovered from the external tank is limited by several factors, such as Orbiter payload, propellant boil-off rate, and transfer efficiency. The amount of recoverable propellant available for use as OTV fuel would be further limited by the number of Shuttle flights from which propellant could be derived, i.e., those flights going to orbit at the same inclination (28.5 degrees) as the OTV space base. Although the technical problems of the Honeybee concept can probably be overcome, it seems likely that, at least at some point in time, demand for OTV traffic will exceed capabilities for ET propellant recovery.

Consequently, an alternative means of providing low-cost propellant has been suggested (see Book 2): the dedicated ET tanker. This Shuttle-derived vehicle could deliver adequate amounts of propellant to the Space Station on a relatively small number of missions. Although propellant delivery via ET tanker would by no means be free, it is estimated that propellant could still be provided for OTV operations at a price of $500 per pound. Since an ET tanker flight would cost less than a typical Shuttle mission (see Table 2-4), this arrangement could also generate profits from the sale of propellant that might benefit all STS users. Throughout the 1990s, 2 to 3 ET tanker flights per year could probably provide all the propellant required for space-based OTV operations.

A flight rate of three ET tankers per year would generate $120 million in annual profits for NASA. If spread over 24 Shuttle flights per year, this could permit a $5-million reduction in the cost of every Shuttle mission, very similar to the benefit achieved with ET propellant recovery in the Honeybee scenario. Since in either case propellant would be provided at $500 per pound, a nominal OTV mission delivering 10,000 pounds of payload to GEO and requiring 27,000 pounds of propellant would incur a cost of about $13.5 million in addition to the $4 million in hardware and operations costs presented in Table 2-2. Total OTV costs per mission, excluding payload delivery costs to LEO, would then be approximately $17.5 million.

Table 2-4. ET Tanker Operations Costs (1984 $)

Cost Component	Shuttle Cost[1] ($M)	ET Tanker Cost[2] ($M)
SRB	24	29
ET	19	19
Launch Operations	19	13
Flight Operations	15	5
Main Engine	3	1
All Other	26	8
Total	106	75

[1]Estimates for 1990, based on 24 flights per year.

[2]ET Tanker Calculations:
ET Tanker Propellant Delivery: 230,000 lb
Cost/lb = $75M/230,000 lb
= $326/lb
NASA Profit: $174 x 230,000 = $40M

2.2.1.3 Reduction in Shuttle Charge Factors. A space-based OTV that could transfer a nominal load of 10,000 pounds from LEO to GEO for $17.5 million would represent a significant improvement in the economics of near-earth spaceflight. To take full advantage of the economic benefits of the OTV, however, it will be necessary to achieve new efficiencies in payload delivery from Earth to LEO. The major economic advantage of the space-based OTV lies neither in its reusability nor its use of propellant delivered to LEO at low cost. The greatest benefit is the space-basing of the launch vehicle itself; OTV users pay only a small fraction of the cost of lifting the upper stage to LEO, the equivalent of about $0.5 million per OTV mission (see Table 2-2). By contrast, the user of an expendable upper stage must pay the full cost of lifting the upper stage to LEO, which could range from $17 million for a PAM-D (based on its use of about 10 feet of Shuttle cargo bay length) to over $80 million for a fully-fueled Shuttle-Centaur, which requires a dedicated Shuttle flight. Even if the weight-dominated upper stages could be launched to LEO and fueled in orbit with low-cost propellant, the cost of launching the dry upper stage to LEO would still be high. An unfueled Centaur G would consume 19.5 feet in cargo bay length and cost $36 million to launch; the longer Centaur G', at 29.1 feet, would cost over $53 million.

Although the propsect of paying only $0.5 million of the OTV delivery cost to LEO seems attractive, the OTV user would still need to pay the cost of having his payload delivered to LEO, which could easily exceed that of the OTV mission itself. Geosynchronous payloads have always been designed to be stowed in a long and thin envelope for compatibility with expandable launch vehicles such as the Delta and Atlas-Centaur. If these payloads are redesigned to make efficient use of STS cargo bay space, then the full benefit of space-basing the upper stage can be realized.

An an example, consider the inertial upper stage (IUS), which weighs approximately 45,000 pounds, and is used to launch payloads such as the Tracking and Data Relay Satellites (TDRS), which weight about 5,000 pounds. Eliminating the IUS vehicle from the cargo bay through space-basing of OTVs can reduce the total Shuttle payload weight from 50,000 to 5000 pounds. This is a reduction in weight load factor from 0.77 to 0.07, a potential savings in Shuttle costs of nearly $75 million. The TDRS spacecraft, however, occupies nearly 18 feet of cargo bay length, creating a length load factor of 0.3, four times as great as the reduced weight load factor.

After removing the IUS upper stage, the TDRS would become a length-critical payload, meaning the Shuttle charge would be based on its length rather than its weight. Rather than a Shuttle price of $8.5 million (for a 5,000-pound payload that is weight-critical, i.e., not exceeding 4.6 feet in length) the TDRS would incur a charge of over $33 million, based on its 18-foot length. The potential $75 million benefit of space-basing the TDRS upper stage is reduced by $25 million, due to the satellite's length.

This still represents a net saving of $50 million in Shuttle charges, made possible by the fact that TDRS is, by communications satellite standards, a relatively length-efficient payload. Most spacecraft are even less length-efficient, to the point at which space-basing of the upper stage provides little or no economic benefit. Table 2-5 lists four of the most common satellites and launch carriers, and compares their launch costs with space-based OTV cost estimates. The space-based OTV is tremendously cost-effective for launching very large satellites such as TDRS and INTELSAT VI, but is less competitive in delivering the smaller Hughes 376 and INTELSAT V-A spacecraft.

2.2.2 BENEFITS TO OTV USERS

2.2.2.1 OTV Benefit to Commercial Users. Table 2-5 brings together all the elements of OTV launch costs and clearly shows the potential benefits of a space-based OTV in launching commercial communications satellites. It also demonstrates the importance of developing more length-efficient satellites for reduction of Shuttle charges. The "OTV Specifications" columns provide the approximate length and weight data that would determine the cost of delivering these payloads to GEO via space-based OTV. The length data reflect the amount of Shuttle cargo bay space these satellites would consume if designed for Shuttle launch to LEO and subsequent transfer to GEO via OTV. The cargo bay length of the INTELSAT VI spacecraft, for example, which would require 28 feet if launched via Shuttle, could be reduced to about 20 feet with removal of the perigee upper stage, which would not be required if an OTV were available.

Table 2-5. OTV Cost Comparison (1984 $)

		Current Costs ($M)			OTV Specifications		OTV Costs ($M)			
Satellite	Possible/ Present Carrier	Hard-ware	STS	Total	Payload Length (ft)	Payload Weight (lb)	STS	OTV	Total	OTV Benefit ($M)
INTELSAT V-A	Atlas-Centaur	55	-	55	21	2000	39	4	43	12
INTELSAT VI	Titan	90	-	90	20*	4000	37	7	44	46
Hughes 376	PAM-D	6	17	23	9	1300	17	4	21	2
TDRS	IUS	55	90	145	18	4700	33	8	41	104

*Would be 28 feet with perigee stage used for STS launch

The weight data influence the OTV transfer cost, and this charge is calculated as

OTV Charge = (Satellite weight - 10,000 lb) x $17.5 million

where the quantity in parentheses represents the percent of OTV lift capacity used (assuming a nominal total load of 10,000 pounds) and $17.5 million is the OTV mission cost (derived earlier). It is assumed that the OTV will never carry more than four separate payloads at once, hence the minimum OTV charge is 1/4 x $17.5 million or approximately $4 million, even if each satellite's weight is under 2500 pounds. By adding the STS cost to LEO to this OTV charge, we get the total cost to GEO.

The OTV is less competitive with the Atlas-Centaur and PAM-D, not because these launch systems are particularly inexpensive, but because payloads that use these systems are not ideally configured for space-basing of their upper stages. The INTELSAT V-A spacecraft, for example, is actually longer than the much heavier (and more capable) INTELSAT VI satellite, because INTELSAT V-A was not designed for Shuttle launch.

Similarly, the very popular Hughes 376 satellite, although comparatively light in weight, is not designed to minimize its use of Shuttle cargo bay space, but to utilize the 10 feet of cargo bay space used by the PAM-D upper stage. The Hughes 376 is presently mounted atop the PAM-D in its stowed configuration, and hence there is no economic incentive for reducing its length to less than the 10 feet that it and the PAM-D presently consume.

Removal of INTELSAT VI's built-in upper-stage boost capability is a key to making it a more length-efficient payload. A more dramatic example of potential OTV benefits, however, is provided by the TDRS, which, without a built-in upper stage, relies on the IUS. Not only does the IUS add nearly $50 million to the STS cost for TDRS, but the IUS stage itself costs about $55 million, making the TDRS the most expensive civilian satellite to launch via Shuttle. A space-based OTV could hence reduce TDRS launch costs by over two-thirds, a total economic benefit of greater than $100 million per satellite.

Figure 2-5 illustrates the criticality of the length-efficiency of payloads in achieving the economic potential of a space-based OTV. The costs of launching 2500-, 5000-, and 10,000-pound satellites via OTV are given as functions of the cargo bay length they require for Shuttle launch to LEO. The impact of the cargo bay length of payloads delivered to LEO on OTV economics is analyzed further in Section 2.2.3.

For comparison, launch costs for the PAM-D, PAM-A, and various expendable launch vehicles (with their payload capacities to GEO, in parentheses) are provided. From this graph a number of important conclusions about OTV operating costs can be drawn.

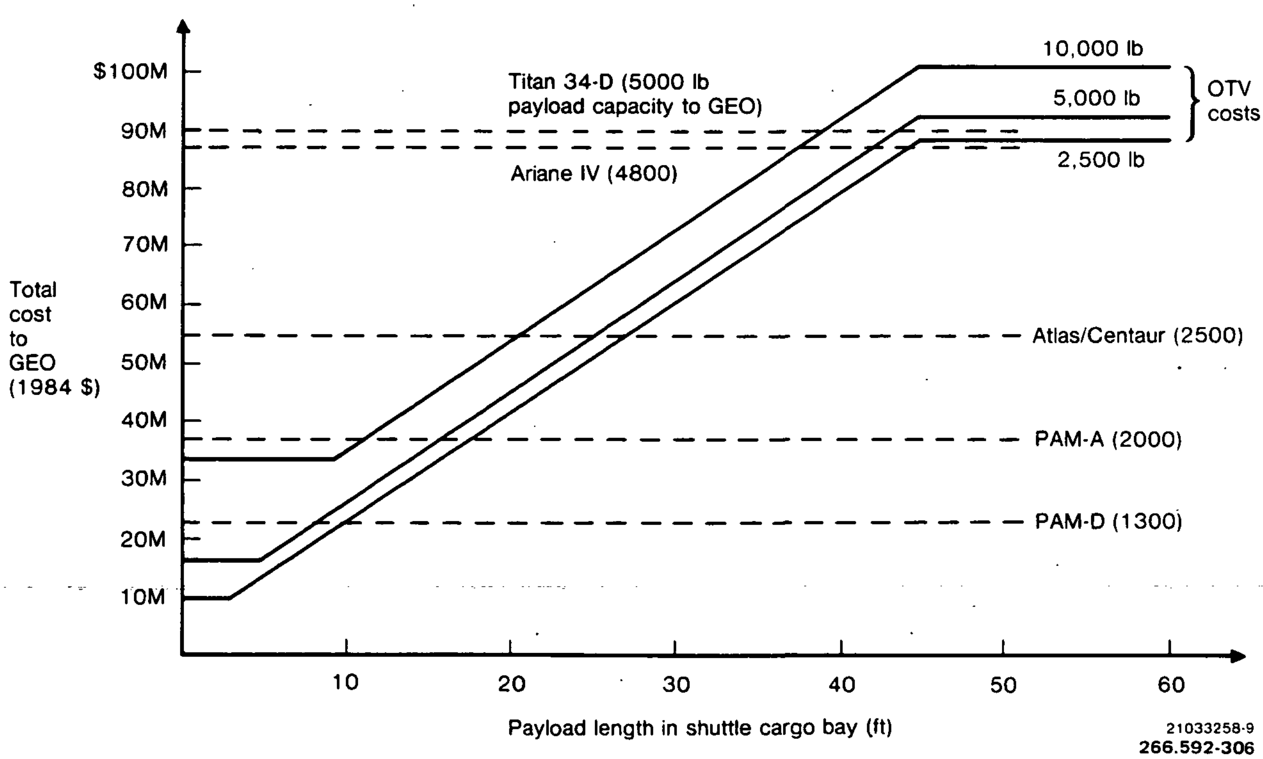

Figure 2-5. Cost to GEO as a Function of Payload Length

Most obvious is the sensitivity of OTV cost to the amount of Shuttle space required for delivery of OTV payloads to the Space Station. The cost of launching a 2500-pound payload to GEO, for example, can range from about $10 million to nearly $90 million, depending on its Shuttle load factor. (In Figure 2-5, it is assumed that all payloads are length-dominated, i.e., consuming a greater fraction of Shuttle length capacity than weight capacity. Virtually all geosynchronous communication satellites fit in this category.)

It is also evident from Figure 2-5 that the OTV can have a substantial cost advantage over all of its present-day competitors, as long as its payloads use Shuttle space efficiently. This benefit is greatest and easiest to obtain for heavier payloads; 10,000-pound satellites (which would require the equivalent of two Titan or Ariane launches) are at most half as expensive to launch via OTV, even if they require entire Shuttle flights for delivery to LEO.

Achieving large benefits with smaller payloads is a greater challenge, but still possible. The OTV becomes competitive with the PAM-D for payloads that require less than 10 feet of cargo bay length and with the PAM-A and Atlas-Centaur for payloads under 20 feet. Payloads in the 5,000-pound class can be launched more cheaply via OTV if they remain under 40 feet in length.

As illustrated in Table 2-5, heavier communications satellites such as INTELSAT VI and TDRS are sufficiently length-efficient for economical OTV delivery. The OTV has little or no benefit, however, in launching lighter satellites such as the Hughes 376, because of their high length-to-weight ratio. Since the majority of communications satellites launched today are in this latter class of lighter spacecraft, the economic viability of the OTV for commercial users will, to some degree, be dependent upon changing the present design philosophy of the space communications industry.

An intermediate solution to the problem of maximizing the benefits of the OTV is to reduce the length of present satellites by removing propulsion stages and deployment apparata that would not be required if a Space Station and OTV were available. The Hughes 376, for example, could be modified to reduce its Shuttle charge factor from 0.21 (with the PAM-D upper stage) to about 0.16. The economic impact of this would be a reduction in Shuttle costs of about $4 million per satellite launched. The total cost to GEO for such a satellite would be less than $18 million.

Modification of existing satellites in this manner may be a relatively inexpensive way to reduce communications satellite launch costs. To take full advantage of the benefits of the Space Station in launching communications satellites, however, an entirely new design strategy should be employed. Communications satellites of the Space Station era should be delivered to the Space Station in containers especially designed for efficient Shuttle manifesting, and should be assembled and reverified in LEO. In support of this study, the conceptual design of a new satellite, the SX, was developed as a means of meeting these requirements.*

*The SX satellite design is SPACECOM proprietary information, so illustrations of SX design were not available for publication in this document.

The SX concept was developed by Spacecom, as a subcontract task for GDC's Space Station study, and represents a potential breakthrough in the reduction of satellite launch costs. The SX satellite is packaged for Shuttle launch as modular components to be assembled in LEO, and requires less than 5% of the Shuttle's load capacity. In its special containers, the SX consumes less than half of the Shuttle cargo bay cross-sectional area and less than six feet of cargo bay length. Hence two satellites could be launched and jointly require less than one-tenth of the available cargo bay space.

In the SX launch configuration, solar power arrays are stored in containers beside the boxes housing the major electronics components of the spacecraft. Despite the minimal volume required, the 2500-pound SX would have a high communications capacity, roughly 4 times the capacity of present-day communications satellites. This means the SX has about twice the capacity of the INTELSAT VI spacecraft, the most capable and advanced commercial communications satellite currently under development. The economic significance of the SX is substantial. The Shuttle charge factor for the SX, as long as at least two are launched on any Shuttle flight, is 0.067, for a Shuttle charge of under $6 million. The total cost to GEO for the SX is less than $10 million, about one-fifth to one-tenth of what it costs to launch a satellite of similar capability today. Table 2-6 compares the SX launch cost with those of other satellites, including a modified Hughes 376, to show the great potential economic benefits of utilizng the space-based OTV to launch a new class of communications satellites.

2.2.3 <u>OTV BENEFITS ANALYSIS</u>. To analyze the economic benefits of the space-based OTV, it is desirable to have these benefits calculated on a "per-OTV mission" basis. Having benefits established on a per-satellite basis, as in the preceeding parts of this section, is useful in quantifying the potential benefit to a particular user. To determine the sensitivities of these benefits to OTV cost factors, however, the per-OTV mission basis is more valuable because the OTV costs are calculated on a per-OTV mission basis as well. A change in any OTV cost variable, such as propellant delivery cost, can then be evaluated in terms of its impact on OTV benefits.

Table 2-6. Satellite Launch Cost Comparison (1984 $)

Satellite	Lower Stage	Shuttle/ Lower Stage Cost	Upper Stage	Upper Stage Cost	Total Cost to GEO
TDRS	Shuttle	$ 90M	IUS	$ 55M	$ 145M
INTELSAT VI	Shuttle	55M	IUS 1st stage	15M	70M
INTELSAT V-A	Atlas	55M	Centaur	Included	55M
Hughes Leasat	Shuttle	28M	Unique	Included	28M
Hughes 376	Shuttle	17M	PAM-D	6M	23M
Modified 376	Shuttle	14M	OTV	4M	18M
SX	Shuttle	6M	OTV	4M	10M

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Finally, by using a mission model that projects the number of OTV missions per year, estimates of annual OTV benefits, and their sensitivity to OTV costs, can be extrapolated from the permission data.

2.2.3.1 OTV Benefits Per Mission. Calculation of economic benefits per OTV mission requires an understanding of what payloads an OTV will typically deliver, and how these payloads would normally be transported if an OTV were not available. Communications satellites provide a good basis for an OTV payload analysis, because: 1) a large portion of OTV traffic will be devoted to launch of communications satellites, and 2) more information is available regarding communications satellite payloads than other candidate OTV payloads.

Communications satellites of the Space Station era can be classified into three weight categories: small (under 1800 pounds), medium (1800-4500 pounds), and large (over 4500 pounds). It is assumed that one OTV mission will be capable of delivering up to four small satellites, three medium satellites, and two large satellites, or some combination of the three types, with a nominal payload weight total of 10,000 pounds. As discussed earlier in this section, a large fraction of OTV delivery costs will be attributed to the costs of launching OTV payloads to LEO via Shuttle. Since these payloads are nearly always length-critical in determining their Shuttle charges, it is important to specify not only the weights of these satellites, but their likely lengths. Table 2-7 shows approximate high, baseline, and low length estimates for the three types of satellites and the Shuttle charges associated with these lengths.

Table 2-7. Estimated Length and Transportation Changes for 1990s Communication Satellites

	HIGH		BASELINE		LOW		
	Length (m)	STS* Charge ($M)	Length (m)	STS* Charge ($M)	Length (m)	STS* Charge ($M)	OTV Charge ($M)
Small (<1800 lb)	3	18	2	12	1	6	4
Medium (1800-4500 lb)	5	30	4	24	1.5	9	6
Large (4500-6000 lb)	7	42	5	30	2	12	12

*Per satellite, millions 1984 dollars

Table 2-7 also shows approximate OTV charges, based on each satellite's share of OTV capability and the OTV cost of $17.5 million per mission. It is assumed that a nominal OTV load would consist of four small satellites, three medium satellites, or either one or two large satellites. Based on this last consideration, the OTV charge for large satellites is based on an "average" load of 1.5 satellites per OTV mission.

In Table 2-8, these data are integrated into a total picture of costs per OTV mission, which are then compared with the costs of accomplishing the same mission objectives without a space-based OTV. The OTV costs shown are on a per-OTV mission basis; for small satellites, the costs shown include Shuttle launch of four satellites to LEO, plus the OTV mission cost of $17.5 million for transfer of the four satellites to GEO, and for medium and large satellites the costs are for launch of three and one and a half satellites, respectively. The OTV competitor costs shown are for accomplishment of the same mission objectives (e.g., launch of four small satellites to GEO), with the competitive system shown in parentheses. By including high, baseline, and low cases for OTV and competitor costs, Table 2-8 provides a comparison of OTV costs with the costs of eight different potential competitors, including several that will not be available for several years, such as the Shuttle-Centaur and the IUS first-stage derivative transfer orbit stage (TOS).

For small satellites, the low cost case is based on the SX satellite design, which optimizes the use of Shuttle cargo-bay space and, as discussed earlier, permits a total launch cost per satellite of $10 million. Restricting the benefits of this satellite design to the category of small satellites represents a conservation assumption, since the SX could weigh up to 2500 pounds and have a greater communications capacity than even the largest satellites used today.

2.2.3.2 OTV Annual Economic Benefits. Table 2-9 presents a mission model for commercial communications satellites developed by SPACECOM in support of this study. Launch projections are given for the three weight classes used in this benefits analysis, and provide the mission model used in this study. The projections in the last three columns are the average figures that constitute this baseline traffic model.

The data from Table 2-8 and 2-9 are combined in Table 2-10 to show the total annual benefit of the OTV in launching commercial communications satellites. In columns 1 and 2, the best-case and worst-case OTV benefit values are shown. These quantities are derived from Table 2-8 as the differences between the lowest OTV cost and the highest competitor cost, and the highest OTV cost and the lowest competitor cost, respectively. The next column in Table 2-10 gives the differences between the baseline cost estimates for the OTV and completitors and in the fourth column the averages of these three quantities are shown.

Columns 5 and 6 in Table 2-10 show the average annual numbers of satellites launched and OTV missions required for these launches, based on data from the years 1994-2000 in the baseline mission model and the OTV capabilities described earlier. The last column shows the annual economic benefit of the OTV for each weight class, based on the average benefit per mission (column 4) and average number of annual missions (column 6). Combining the benefits of the three weight classes yields a total annual economic benefit in OTV launch of commercial communications satellite of $720 million.

Table 2-8. OTV Mission Costs vs Competitor Costs (1984 $)

Satellite Class	Average Number Launched Per OTV	Cost Per OTV or OTV-Equivalent Mission ($M) High	Baseline	Low
Small Satellites				
OTV	4	90	66	40
Competitor		136 (PAM-DII)	112 (LEASAT)	92 (PAM-D)
Medium Satellites				
OTV	3	109	90	45
Competitor		165 (Atlas/Centaur)	123 (Shuttle-Centaur)	114 (PAM-A)
Large Satellites				
OTV	1.5	81	63	36
Competitor		145 (Shuttle-Based OTV)	143 (TOS)	92 (Shuttle/Centaur)

Although an annual benefit of $720 million from OTV operations is significant in itself, this represents only part of the economic potential of the OTV. Launch of DoD and science and applications payloads, which are not included in this mission model, could increase OTV traffic substantialy beyond what would be required for launch of commercial communications satellites. Based on requirements data developed for this study, it can be estimated that these other users will roughly double the commercial mission model. Assuming all users derive a similar economic benefit per OTV mission, the total annual economic benefit from space-based OTV operations, as illustrated in Table 2-11, could be as high as $1.62 billion, with an expected benefit of $1.44 billion per year.

The total OTV mission model for achieving this $1.44 billion per year benefit calls for 162 missions between 1994 and 2000, an average of about 23 OTV flights per year. The total potential previous benefit of OTV operations over this period is <u>$10 billion</u>. A reasonable estimate of actual OTV benefits,

Table 2-9. Satellite Launch Prediction by Mass

YEAR	MODEL A			MODEL B			MODEL C			AVG.		
	SMALL	MEDIUM	LARGE	SMALL	MEDIUM	LARGE	SMALL	MEDIUM	LARGE	SMALL	MEDIUM	LARGE
81	—	—	—	5/3*	0	0	—	—	—	4	0	0
82	9	8.	0	3/2	0	0	—	—	—	5	4	0
83	10	8	1	5/2	2/1	0	5	0	2	5.5	3	1
84	10	9	2	5/3	3/1	0	7	0	2	6	3	1
85	14	8	1	5/3	3/2	1	17	0	0	10	3	1
86	9	12	4	4/4	4/2	2/0	17	2	2	8.5	5	2
87	12	10	6	0/3	4/3	5/0	21	4	0	9	5	2
88	11	12	6	0/4	3/3	9/0	12/7	3/0	3/1	7	4	4
89	14	10	6	0/3	0/3	12/1	10/6	5/0	4/0	7	4	6
90	11	12	7	0/2	0/5	15/1	10/5	3/2	2/1	6	4	5
91	11	12	9	0	0/5	13/1	9/9	3/1	2/3	6	4	6
92	10	13	10	0	0/5	15/3	20/10	3/2	2/2	8	6	6
93	13	11	9	0	0/5	17/3	22/13	1/4	1/3	10	4	7
94	11	10	11	0	0/1	19/7	26/14	0	10/2	10	3	10
95	11	16	11	0	0	20/7	17/21	3/0	8/3	10	4	10
96	8	13	13	0	0	22/9	12/6	3/0	10/7	5	3	12
97	9	13	13	0	0	26/10	17/11	0	11/5	7	3	13
98	11	11	12	0	0	30/11	12/9	0	9/6	6	3	14
99	8	13	14	0	0	33/12	14/10	0	5/6	6	3	14
00	6	13	17	0	0	38/15	17/10	0	11/3	7	3	17
01	8	13	14	—	—	—	—	—	—	8	13	14
02	7	12	18	—	—	—	—	—	—	7	12	18

SMALL UP TO 1800 lbs. (RCA SATCOM/HUGHES 376 CLASS)
MEDIUM 1900-4500 lbs. (FORD INTELSAT V CLASS)
LARGE 5100 lbs.+ (TDRSS CLASS)

*HIGH/LOW MODEL

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however, must take into account market capture considerations. Technically, all 162 missions in the OTV mission model are compatible with the OTV, but for various logistical and political reasons, many will not be carried out with the OTV, regardless of the cost effectiveness and performance of the space-based system. For the purposes of this analysis, it is estimated that the OTV will actually capture three-fourths of these potential missions. This 75% market share translates into a potential OTV economic benefit of

0.75 x $1.44 billion = $1.08 billion

annually, or

0.75 x 162 missions x $62.6 million = $7.5 billion

for the period 1994 to 2000.

Table 2-10. Annual Economic Benefits of OTV in Launching Commercial Communications Satellites (1984 $)

	1	2	3	4	5	6	7
	OTV Benefits Over Competitor (Per OTV Mission) ($M)				Satellites Launched/Yr		Annual
Satellite Weight	Best Case	Worst Case	Baseline Comparison	Average	(Average, 1994-2000)	OTV Missions Required	Economic Benefit ($M)
Small	96	2	46	48	7.3	1.8	86
Medium	120	5	33	53	3.1	1.2	64
Large	109	11	80	67	12.8	8.5	570
Totals	--	--	--	62.6*	23.2	11.5	720

*Weighted average benefit per OTV mission

Table 2-11. Total Annual OTV Economic Benefit (1984 $)

DoD, Science and Applications Increase in Mission Model	Benefit Per OTV Mission ($M)	OTV Missions: Commercial Communications (Annual)	Annual Benefit: Commercial Communications ($M)	OTV Missions DoD, Science and Applications	Annual Benefit: DoD, Science and Applications ($M)	Total Annual Benefit ($B)
75%	62.6	11.5	720	8.6	540	1.26
100%	62.6	11.5	720	11.5	720	1.44
125%	62.6	11.5	720	14.4	900	1.62

2.2.3.3 Sensitivity Analysis. Although these data reflect a very favorable view of potential OTV benefits, it should be noted that this analysis is based on a large number of assumptions with wide ranges of uncertainty. The key assumptions, and their high, low, and assumed values, are listed in Table 2-12a.

To establish the sensitivity of OTV benefits to these variables, we set up the following equation using the variables in Tables 2-12 and 2-12a.

$$B = m \times [c - \underline{((u+d)/f + (s/20) + (h_1 \times c_1) + (h_2 \times c_2) + (p_1 \times p_2)}$$

$$\underline{+ (t \times p \times \frac{1}{60} \times \frac{1}{0.75}}))]$$

where B is the total annual benefit from OTV operations. The underlined portion of the equation represents the average cost of an OTV mission, which is $62.9 million in the baseline case, and can be derived independently from the data in Tables 2-8 and 2-10. The average competitor cost per mission of $125.5 million was similarly obtained from the competitor cost data in Tables 2-8 and 2-10.

Table 2-12. OTV Benefits Analysis: Definition of Key Variables

Variable Code	Variable	Variable Code	Variable
u	OTV unit cost	c_2	Cost of crew time - ground
d	OTV delivery cost	p_1	Propellants required - per mission
f	OTV lifetime (flights)	p_2	Propellant cost (per pound)
s	Spares cost (per 20 flights)	t	Shuttle: dedicated price
h_1	Crew hours per mission - ground	p	Shuttle: payload length (average)
h_2	Crew hours per mission - ground	c	Competitor cost per mission
c_1	Cost of crew time - space	m	OTV missions per year (average)

Table 2-12a. OTV Benefits Analysis: Key Assumptions (1984 $)

Variable	Low Value	High Value	Assumed Value	OTV Annual Benefit Worst Case	Best Case	Sensitivity
OTV unit cost	$60M	$180M	$120M	$1.08B	$1.09B	Low
OTV delivery cost	$60M	$180M	$120M	$1.08B	$1.09B	Low
OTV lifetime (flights)	60	480	240	$1.03B	$1.09B	Low
Spares cost (per 20 flights)	$10M	$30M	$15M	$1.07B	$1.09B	Low
Crew hours per mission — space	50	500	200	$1.03B	$1.11B	Low
Crew hours per mission — ground	500	5000	2000	$1.08B	$1.09B	Low
Cost of crew time — space	$5,000/hr	$25,000/hr	$10,000/hr	$1.03B	$1.10B	Low
Cost of crew title — ground	$50/hr	$250/hr	$100/hr	$1.08B	$1.09B	Low
Propellants required — per mission	20,000/lb	35,000/lb	27,000/lb	$1.02B	$1.15B*	Low
Propellants cost	$250/lb	$1500/lb	$500/lb	$618M	$1.20B	High
Shuttle: dedicated price	$70M	$100M	$83.3M	$927M	$1.21B	Low
Shuttle: payload length (average)	12 ft	40 ft	24.5 ft	$588M	$1.48B	High
Competitor cost per mission	$75M	$200M	$125.5M	$211M	$2.37B	High
OTV missions per year (average)	10	25	17.3*	$627M	$1.57B	High

*Assumes 75% market share of 23 OTV-equivalent missions per year

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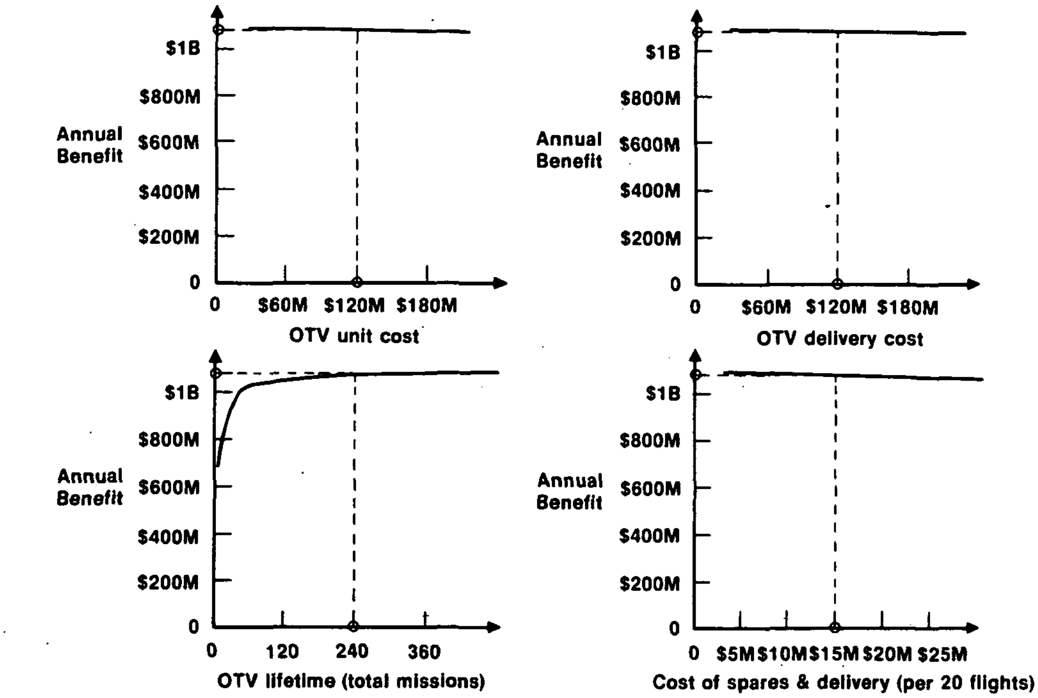
Figures 2-6 through 2-11 graphically illustrate the sensitivity of OTV economic benefits to all of the preceding variables. Figure 2-6 (a through d) shows that the OTV benefit is not at all sensitive to OTV unit cost, delivery cost to LEO, or spares, and is only sensitive to the OTV lifetime if the OTV lasts for fewer than 20 missions (the expected life is 240 missions). Figure 2-7 (a through d) shows OTV benefits to be similarly insensitive to operation costs related to Space Station crew time and ground support labor. This result is somewhat surprising and highly significant. If for example, the amount of Space Station crew time for OTV turnaround were to double (from the assumed 200 man-hours to 400 man-hours), annual OTV benefits would decline by only 4%.

Figure 2-8 (a and b) demonstrates a low to moderate sensitivity of OTV benefits to propellant requirements and delivery cost. The sensitivity to propellant requirements is low, due to this variable's narrow range of uncertainty, but propellant delivery costs could be as great as $1500 per pound (with conventional Shuttle cargo-bay delivery) and hence can influence OTV benefits more significantly. It is important to note, however, that even with propellants costing $1500/pound, the OTV is highly cost-effective, with an annual benefit of over $600 million.

Shuttle-related costs are in fact the greatest determinant of OTV benefits; Figure 2-9 (a and b) shows that OTV benefits are most sensitive to the cost of delivering OTV payloads to LEO via Shuttle, which is a function of the Shuttle price (Figure 2-9a) and the amount of cargo bay space used by the payload (Figure 2-9b). The baseline assumption of 24.5 feet of cargo bay space required for an average OTV mission payload represents only half the length-efficiency of the advanced SX satellite. One OTV load of four SX satellites would require only 12 feet of cargo bay space and if all OTV payloads were this length-efficient the annual benefit of the OTV would rise by nearly 40% over the baseline. It should be noted that an increase in Shuttle price, however, would also increase the costs of most OTV competitors, so the sensitivity of OTV benefits to changes in Shuttle price is probably not nearly as great as indicated in the worst-case (Figure 2-9a).

Figures 2-10 and 2-11 show OTV economic benefits to be highly sensitive to competitor costs and to the OTV mission model. In no circumstance, however, do the OTV benefits drop below $200 million per year. Table 2-13 summarizes the sensitivities, showing that only four variables, propellant delivery cost, Shuttle payload length, competitor cost, and OTV missions per year, have a high impact on OTV economic benefits.

2.2.3.4 Summary of OTV Economic Benefits. The baseline OTV economic benefit of $1.08 billion per year represents a great potential advantage over all other methods of payload delivery to GEO (Figures 2-12 and 2-13). The OTV is the most economically attractive use of a manned Space Station, and its potential benefits do not appear to be dependent on OTV cost or performance factors. A worst-case analysis with all 10 OTV cost variables set at their worst-case levels shows the OTV to maintain an economic benefit of over $100 million per year. The OTV loses its benefit only in two extreme cases: if OTV payloads require very large amounts of Shuttle cargo by length for delivery to LEO, or if OTV competition costs drop well below the costs of any presently envisioned alternative.



Conclusion: OTV economic benefits have extremely low sensitivity to vehicle production & maintenance costs

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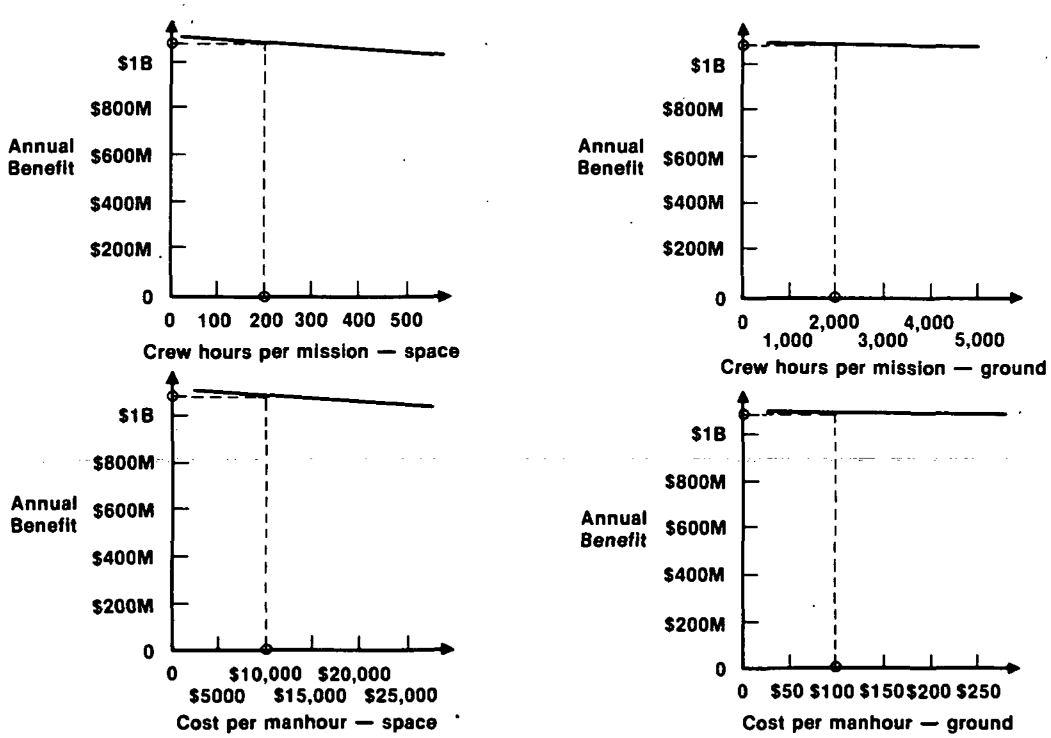
Figure 2-6. OTV Sensitivity Analysis: Vehicle Production and Maintenance (1984 $)



Conclusion: OTV economic benefits have low sensitivity to crew operations costs

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Figure 2-7. OTV Sensitivity Analysis: Crew Operations Costs (1984 $)

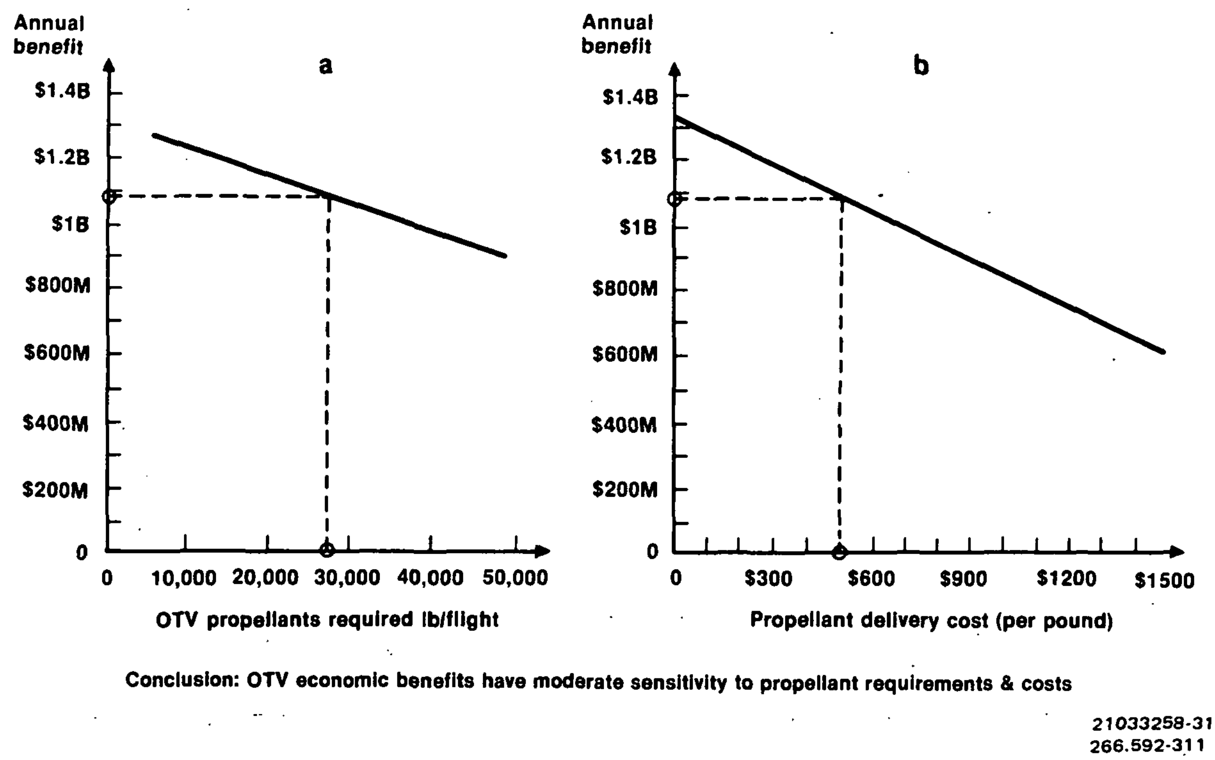

Figure 2-8. OTV Sensitivity Analysis: Propellant Requirements and Costs (1984 $)

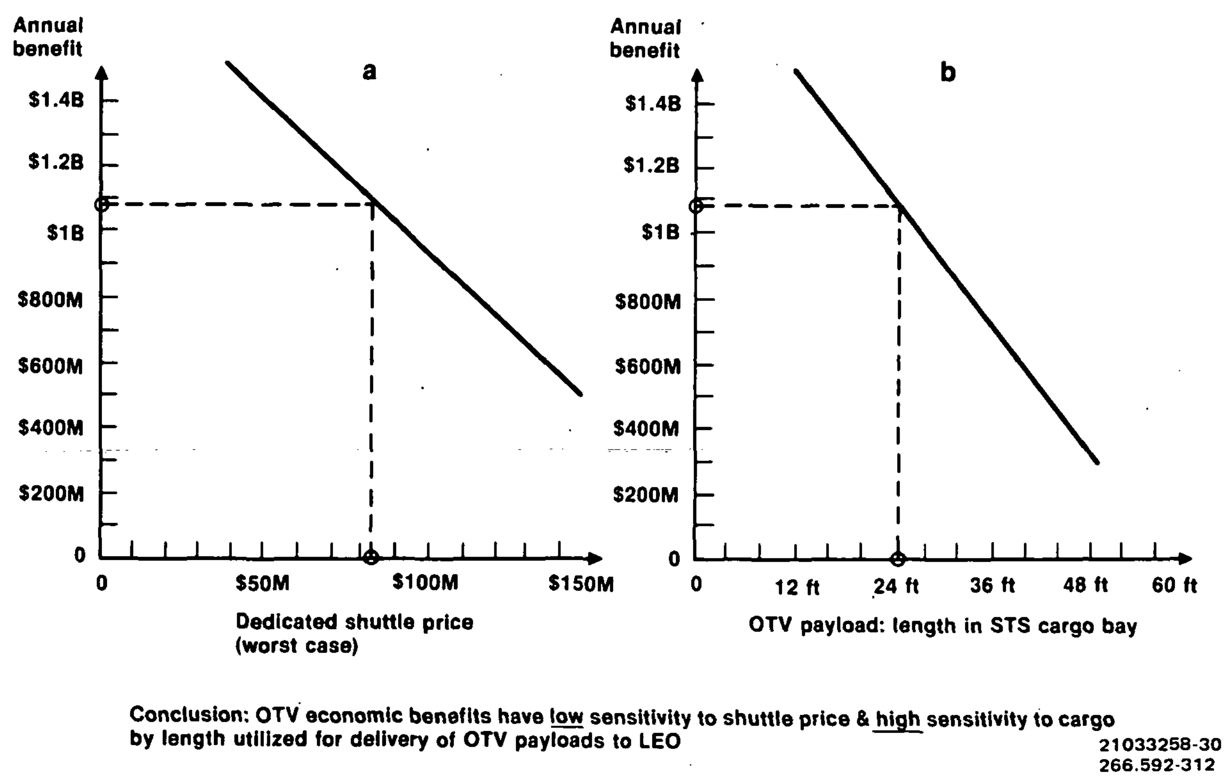

Figure 2-9. OTV Sensitivity Analysis: Shuttle-Related Costs (1984 $)

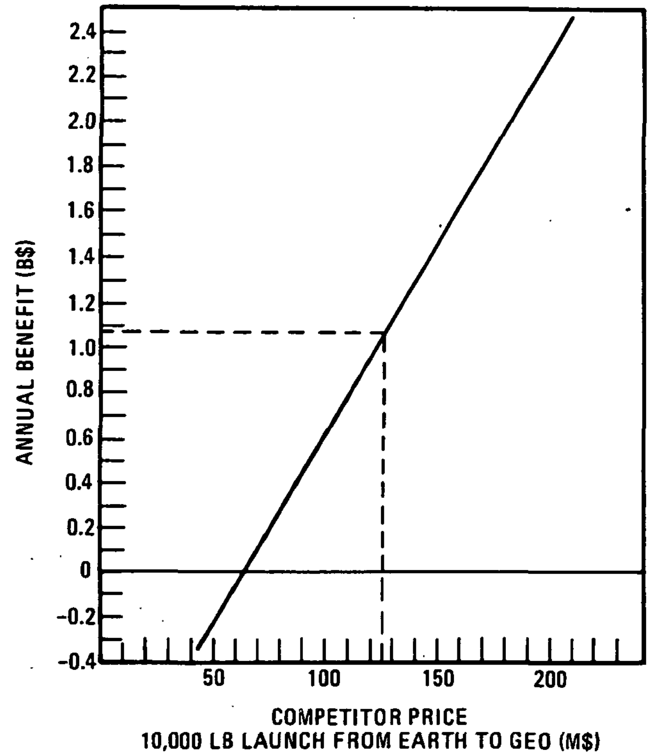

Figure 2-10. OTV Sensitivity Analysis: Competitor Price (1984 $)

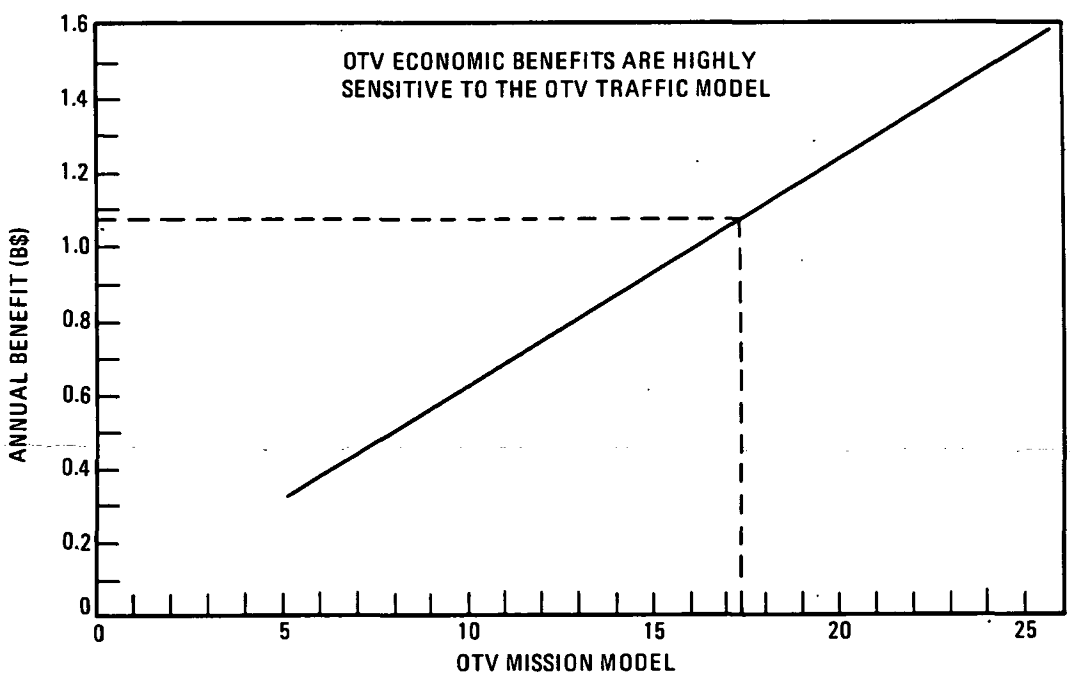

Figure 2-11. OTV Sensitivity Analysis: Number of OTV Missions per Year (Average)

Table 2-13. Summary of Sensitivities - OTV Benefits

Variable	OTV Annual Benefit Worst-Case	Best-Case	Sensitivity
OTV Unit Cost	$1.08B	$1.09B	Low
OTV Delivery Cost	$1.08B	$1.09B	Low
OTV Lifetime	$1.03B	$1.09B	Low
Spares Cost	$1.07B	$1.09B	Low
Crew Hours per Mission: Space	$1.03B	$1.11B	Low
Crew Hours per Mission: Group	$1.08B	$1.09B	Low
Cost of Crew Time: Space	$1.03B	$1.10B	Low
Cost of Crew Time: Ground	$1.08B	$1.09B	Low
Propellants Required	$1.02B	$1.15B	Low
Propellant Delivery Cost	$618M	$1.20B	High
Shuttle: Dedicated Price	$927M	$1.21B	Low
Shuttle: Payload Length	$588M	$1.48B	High
Competition Cost per Mission	$211M	$2.37B	High
OTV Missions per Year	$627M	$1.57B	High

Sale of OTV propellant, recovered from the Shuttle external tank or delivered via ET tanker, represents an additional potential benefit of OTV operations. If the ET tanker is used as a baseline scenario, the expected profit of $80 million from two ET tanker flights annually would raise total economic benefits of OTV operations to $1.16 billion annually. As suggested earlier, this profit from propellant sale for OTV operations could be used to help reduce Shuttle prices, a potential benefit to all STS users. If the OTV is in fact as economically attractive as it appears, NASA might consider selling propellant at an even higher price than the assumed $500 per pound to increase the benefit to STS users. At a price of $1000 per pound, NASA could generate $310 million in profit from ET tanker operations, with only a 20% reduction in OTV benefits caused by the higher propellant price. This profit could permit an STS price reduction of nearly $13 million per Shuttle flight, based on 24 Shuttle flights per year.

Since Space Station and OTV research and development costs were not included in this analysis, the economic benefits of the OTV should be viewed with some moderation. With a net operating benefit of $1.16 billion per year, however, it can be seen that even a very substantial investment in development of an OTV, OTV base, and ET tanker could be repaid in a relatively short period of time. In private industry, an annual profit of $1.16 would represent a good return on any investment of up to $7 billion, which is roughly commensurate with the expected cost of developing a Space Station OTV capability. Space Station costs will be discussed in greater detail in Chapter 2 of this volume.

Cost Factor (per 10,000 lb of payload)	Mission Cost	
	OTV	Competitor Average*
Upper stage cost	$ 0.5M	$ 17.0M
Upper stage delivery to LEO	$ 0.5M	$108.5M
Payload delivery to LEO (OTV only)	$45.4M	0
Operations/spares costs (OTV only)	$ 3.0M	0
Propellant delivery to LEO (OTV only)	$13.5M	0
Total	$62.9M	$125.5M

*PAM-D, PAM-D II, Leasat, PAM-A, Atlas/Centaur, Shuttle/Centaur, TOS, shuttle-based OTV

Economic benefit per OTV mission = $125.5M − $62.9M = $62.6M
Average number of OTV missions per year (1994-2000) = .75 × 23 = 17.3

OTV economic benefit per year = $62.6M × 17.3 = $1.08 billion

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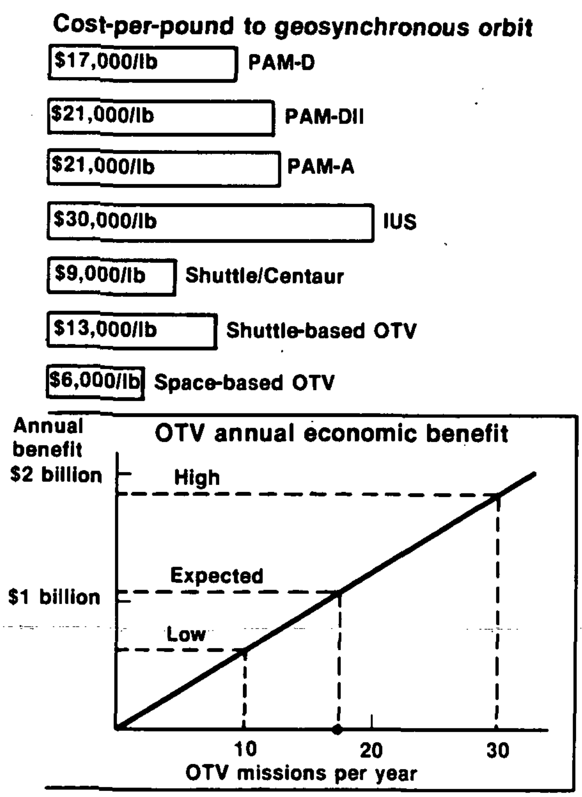
Figure 2-12. OTV Economic Benefits Analysis (1984 $)



Space-based OTV

- Greatest quantifiable economic benefit of space station program
- Expected annual benefit of over $1 billion
- Maximizes efficiency of space transportation system
- Significant parameters
  - Shuttle payload delivery cost to LEO
  - Propellant delivery cost to LEO
  - OTV mission model
  - Competitor cost
- Benefits generally insensitive to
  - OTV production costs
  - OTV operations costs (ground & space)
  - OTV spares/refurbishing costs

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Figure 2-13. Economic Benefits: Space-Based OTV

2.3 SATELLITE SERVICING

2.3.1 OVERVIEW OF SATELLITE SERVICING BENEFITS. As described in Volume II of this report, the Space Station will be utilized for the servicing of satellites in two distinct ways. It will play a support role in the "in-situ" servicing of satellites that can be repaired, refurbished, or upgraded at their orbital locations, and a more prominent role in the complex servicing tasks that require satellites to be brought to the Space Station for servicing. For both of these types of servicing activities, the Space Station should provide substantial economic benefits.

One way to evaluate the economic benefits of satellite servicing would be to compare the cost of performing Space Station servicing oprations with the cost of satellite servicing by alternate means. This was the methodology used in the OTV benefits analysis, where estimated OTV mission costs were contrasted with the launch costs of various potential competitors, such as expendable launch vehicles and Shuttle upper-stage boosters. This cost-based analytical approach was more appropriate than a revenue or value-based method because the value of the satellites launched, although easily exceeding the OTV launch costs, would have given little insight into the competition-sensitive market value of the OTV service.

In assessing the benefits of satellite servicing, however, the cost-comparison approach has important shortcomings. Whereas there exist many alternatives for launching satellites, thus providing a broad base for comparison in the calculation of OTV launch cost benefits, the only competition in the satellite servicing business would be the Space Shuttle. Moreover, the cost of satellite servicing, by Shuttle or Space Station based means, is not as obviously dominated by servicing value. Successful launch of a new satellite may promise revenue far in excess of nearly any associated launch costs, but servicing of an existing satellite can be economical only in certain special circumstances. The satellite must first be servicable; it cannot be too old, obsolete, or inaccessible for effective servicing, and the value of the serviced satellite's remaining operations must exceed the servicing and subsequent operations costs.

As a result, the value of satellite servicing can best be estimated by a value-based, rather than a cost-based technique. The cost of a servicing mission is first compared with the expected value of the servicing operation, based on the satellite's lifetime, value, and the portion of its lifetime and value restored by the servicing. This quantity is based on such factors as the criticality of the situation requiring servicing and the expected life of the satellite after servicing. Once these relationships are identified, a cursory cost-based analysis can be performed to ensure that Shuttle-servicing is not more cost-effective (than utilizing the Space Station) in meeting the servicing objectives.

2.3.1.1 Value-Based Estimating for Satellite Servicing Benefits. During the Space Station era, three different types of servicing missions are likely to be performed: scheduled maintenance, unscheduled maintenance, and unscheduled upgrading. Nearly all servicing operations should fit within the first two classifications where satellites are restored to their intended capabilities at planned intervals after certain mission objectives have been met (scheduled maintenance) or at random intervals after unplanned malfunctions (unscheduled maintenance). Since it is difficult to predict when upgrading services will be scheduled and performed, and since these activities may be very rare, an economic analysis based on scheduled and unscheduled maintenance provides sufficient data for the purposes of this study. An approximation of the economic benefit of a satellite servicing mission is provided by the equation:

$$b = [m \times (e/d) \times (1 + u)] - c$$

The mission criticality factor, m, refers to that portion of the satellite's capabilities that are being restored. Although this term is generally used in reference to unplanned malfunctions of science and applications satellites[1], its definition is broadened here to include scheduled and unscheduled maintenance on all types of spacecraft. In the servicing benefits equation, a mission criticality factor of 0.3, for example, means that 30% of the satellites total mission capabilities are restored by the servicing operation.

The life extension factor, e, represents the number of years of operations added to the spacecraft's life by the servicing mission.

This number is then divided by the design life, d, to obtain a time-related function of the value of the servicing operation. The design life is the total number of years of operations over which the investment in the satellite is considered repaid. The expected life of a certain satellite might actually exceed its design life, but the design life function retains its usefulness as a measure of the relative value of e, the number of spacecraft operating years provided by the servicing mission.

As an example, a satellite of a certain given value, v, and given a design life of 10 years would provide v/10 units of value per year. If e were equal to 4, then the value of the servicing mission would be e/d = (4/10)v, multiplied by the mission criticality factor m. If m remained 0.3, then the actual value of servicing would be 0.3 x (4/10)v or 0.12 v.

The next terms in the benefits equation, l and u, are intended to provide an approximation of this v function, the satellite value. The launch cost, l, plus the unit cost of the satellite, u, is used as a measure of the minimum vaue of the satellite. Unit cost is the recurring (production) cost of the satellite, plus that portion of nonrecurring (development) costs attributable to that unit. In the example cited above, if the launch cost were $100 million and the unit cost were $100 million, then the satellite lifetime value v would be $200 million, and the economic benefit of the servicing mission would be

$$b = [(0.3 \times (4/10) \times (\$100M + \$100M] - c$$

[1] Timmins, A.R., "A Study of Total Space Life Performance of GSFC Spacecraft," NASA Technical Note TN d-8017: Goddard Space Flight Center, July 1975.

or $24 million minus c, the cost of the servicing mission. It is in the reduction of this final variable, c, the cost of satellite servicing, that the Space Station would have its economic value in satellite servicing.

2.3.1.2 <u>Cost of Space Station Satellite Servicing</u>. Satellite servicing from a Space Station will have three basic cost elements, which can be classified as capital, consumables, and labor. Capital costs include the cost of operating the "common" servicing equipment that is used repeatedly over the course of many different servicing missions. The OTV and Tele-Operator Maneuvering System (TMS) are the prime examples of common servicing equipment; capital costs are those costs involved in producing and operating these systems. An unmanned servicing module, which can be used in conjunction with the OTV and/or TMS, is another key capital good.

Consumables are the supplies and parts that are devoted to single missions, and must be completely replenished or replaced for subsequent servicing tasks. Examples of consumables are propellant for the OTV and TMS, and those spare parts that are substituted for failed or worn parts in serviced satellites such as avionics, batteries, RCS (reaction-control system) units, etc. The major costs involved in the provision of consumables will be in their transportation to the Space Station. These transportation costs should in most cases exceed the costs of the supplies themselves, since, utilizng the Space Shuttle for delivery to LEO, transportation costs in the $1200 to $2000 per pound range can be expected. Delivery of OTV and TMS propellant to the Space Station should represent a large portion of these consumable costs.

Labor costs are the manpower costs for Space Station crewtime and ground support for servicing missions, and is of course a direct function of mission duration and complexity. As will be the case with all Space Station missions, the amount of on-orbit crew time will be minimized in favor of automation and ground support, since on orbit manpower will, in all likelihood, cost a minimum of two orders of magnitude more than ground support manpower.

The particular mix of capital, consumables, and labor costs associated with any servicing mission will be influenced primarily by the proximity of the serviced asset to the Space Station. For this reason above all others, as many satellites as possible will be orbiting with the Space Station, at the same inclination and at altitudes that will permit servicing at desired intervals. For the servicing of satellites and/or free flyers in LEO or HEO, OTV operations will not be required, sparing a major element of servicing costs. The means of transportation to these satellites will be the TMS, which can make orbit plane changes of up to 8 degrees, and altitude changes of up to 600 miles, depending on mission parameters such as payload weight.

Servicing missions to orbits and inclinations beyond the range of the TMS, however, will require the use of the OTV. Whenever possible, servicing tasks will be performed in situ, because return of satellites to the Space Station for servicing, and subsequent replacement in orbit, would require two round-trip OTV missions, at considerable cost. For in-situ servicing, the OTV will utilize an unmanned servicing module as will the TMS. For servicing missions beyond the range of the TMS, OTV transportation costs will probably be the greatest single satellite servicing cost factor.

Table 2-14 summarizes the major components of satellite servicing mission costs. It is assumed that a TMS supply module will be delivered to the Space Station via Shuttle after every 20 TMS missions, just as an OTV supply module will carry one refurbished OTV engine, plus RCS, avionics, and other spares sufficient for 20 missions. These costs are detailed in Section 3, but are presented below for reference. As these estimates are somewhat speculative, for convenience they are summarized by assessing the total cost of a TMS servicing mission at about $5 million and an OTV servicing mission at $11 million.

Table 2-14. TMS/OTV Mission Cost Summary

TMS		OTV	
Capital			
Unit $160M/240 flts = $0.67M		- $120M/240 flts = $0.50M	
Transportation $6M/240 flts = $0.025M		- $120M/240 flts = $0.50M	
Consumables			
Engine - $2M/20 flts = $0.05M			$0.10M
Avionics - $1M/20 flts = $0.05M			$0.05M
RCS - $1M/20 flts = $0.05M			$0.05M
Misc - $1M/20 flts = $0.05M			$0.05M
Transportation - $10M/20 Flts =	$0.50M		$0.50M
Propellant - 1500 lb @ $500/lb =	$0.75M	- 12,000 lb @ $500/lb =	$6.0 M
MPE/S*	$0.50M		$0.50M
Labor			
Ground - 2000 hr @ $100/hr. =	$0.20M		$0.20M
Space - 200 hr @ $$10^4$/hr =	$2.0 M		$2.0 M
Total	$4.9 M		$10.5 M

*MPE/S = Mission Peculiar Equipment and Structures

It is important to note at this point that these servicing mission costs are dramatically lower than the costs of TMS or OTV servicing from the Space Shuttle. In the case of the TMS, Shuttle servicing would save about $3.25 million in transportation of consumables and labor on-board the Space Station, but would add about $16.5 million in Shuttle-related mission costs. Use of the Space Station as a TMS base hence saves $13.25 million per servicing mission as compared with using the Shuttle for TMS servicing. The Space Station advantage in OTV servicing is even more obvious, since a Shuttle-OTV servicing mission (if at all possible) would require a dedicated Shuttle flight and hence cost in the neighborhood of $100 million. These relationships, which are discussed in greater detail in Section 3, verify the applicability of a value-based analytical method to the assessment of Space Station satellite servicing benefits.

2.3.2 BENEFITS TO SATELLITE SERVICING USERS

2.3.2.1 Satellite Servicing Benefits to Commercial Users. Evaluating the economic benefits of satellite servicing to commercial users is a particularly difficult task. Commercial communications satellites would appear logical candidates for servicing, due to their large numbers (an estimated 200 to 300 will be launched during the 1990s) and great revenue-producing capability ($50 to $150 million annually per satellite, depending on number of transponders). Upon closer examination, however, the issue becomes more clouded.

Commercial communications satellites are among the most reliable spacecraft launched, so most will probably rarely need emergency servicing. Communications satellites are also less expensive to replace than most other satellites, which reduces the attractiveness of servicing those that do break down. The potential benefits of unscheduled and scheduled maintenance are further diminished by the rapid rate of obsolescence of communications satellites. Finally, the great distance of most communications satellites (in GEO) from a low-orbit Space Station will raise the cost of servicing missions considerably.

Commercial materials processing in space (CMPS) may benefit from satellite servicing by the use of the TMS for product change-out on co-orbiting free-flyers. Resupply modules containing finished products can be replaced on the free-flyers with modules containing raw material to be processed, but since Shuttle flights would be required for transport of the resupply modules between Earth and the Space Station, it is difficult to envision significant cost savings by involving the Space Station and TMS in this process. One potential benefit is in integration of raw materials with reusable resupply modules at the Space Station, thereby reducing the Shuttle costs involved in transport of raw material to LEO. Finished products would be extracted from the resupply modules after harvesting by TMS, and returned to Earth via Shuttle in the same lightweight containers used for shipment of raw material to LEO.

Remote-sensing satellites could benefit from OTV or TMS servicing, but such benefits are as difficult to predict as those for other commercial users. As in materials processing, the nature of commercial involvement in the remote-sensing field during the 1990s is a key uncertainty. It is therefore difficult to draw conclusions about satellite servicing requirements for commerical Space Station and satellite users, and nearly impossible to quantify what economic benefits, if any, would result from such activity.

2.3.2.2 <u>Satellite Servicing Benefits to Science and Applications Users</u>. The science and applications user community provides a much better basis for he evaluation of satellite servicing benefits than do commercial users. Science and applications satellites and platforms generally are far more expensive and difficult to replace than commercial satellites, and usually are more complex and prone to malfunctions that make them candidates for servicing. Many will also be designed for periodic maintenance, and will be within a serviceable proximity to the Space Station and its servicing capabilities. Servicing of science and applications satellites also lends itself well to the type of value-based benefits analysis described earlier in this section. They are not revenue-producing assets per se, but their value can be taken as a direct function of their cost. By combining historical data on satellite cost and performance with projection of future (Space Station era) satellite characteristics, we can examine the equation

$$b = [m \times (e/d) \times (1+u)] - c$$

and develop first-order estimates of satellite servicing benefits.

Substantial data exist on mission criticality factors of malfunctions among science and applications satellites. A study of 57 NASA satellites by Goddard Spaceflight Center[2] provides a breakdown of malfunctions according to frequency and severity. Of 513 malfunctions recorded over a three-year period, 85% were considered minor, with less than a 10% loss of spacecraft capability. For such minor malfunctions ($m < 0.10$), satellite servicing would usually not be economical.

As an initial ground rule, then, it is assumed that satellite servicing will be considered only for those satellites with malfunctions causing greater than a 10% loss in mission capability ($0.10 \leq m \leq 1$). Of the satellites studied by GSFC, the typical satellite experienced a malfunction in this severity range once every two years. The expected mission criticality of these losses was 0.44. Although this study is somewhat dated, experience with more modern satellites has supported these early findings.[3] Reasons for this are not fully understood, but apparently advances in subsystem reliability have been offset by increases in spacecraft complexity.

Assuming this trend continues into the 1990s, we can make two important conclusions regarding the satellite servicing benefits equation. First, the mission criticality factor can be assigned a nominal value of 0.44, for those malfunctions that require servicing.

[2] See footnote 1.

[3] Shockey, Edward F, NASA Goddard Space Flight Center, personal communication, 2 February 1983.

Second, the mean time between servicing missions for any science and applications satellite can be estimated at two years, meaning the value e in the benefits equation equals 2. A typical servicing mission, then, would be expected to restore 44% of a satellite's full capability, for a period of two years.

The satellite design life, d, is more difficult to project from the Goddard data. Most satellites of that era (1960-1975) were designed for very short lives - often one to two years or less.[4] Science and applications satellites today, however, are typically designed for longer lives, often in the three-to seven-year range. The highly specialized scientific experiments planned for operations in the 1990s have an average expected life of about five years. The less advanced applications satellites of the Space Station era may have even longer design lives; five to ten years might be considered average for a weather or remote-sensing satellite. Based on these data, a typical design life for Space Station-serviceable satellites can be estimated roughly at about seven years.

Launch and unit costs of satellites, the next two elements of the benefits equation, are similarly difficult to predict. Launch costs for relatively small applications satellites can be as low as $20 to $30 million, but the large scientific instruments planned for Shuttle launch over the next two decades could cost as much as $100 million to deploy. An example of the latter class of payload is the Large Deployable Reflector, which weighs 25,000 kg and will consume an entire Shuttle flight. Based on the information available, an average launch cost of $40 million would be a reasonable expectation for the 1990s time-frame. A rough projection of average stellite unit cost (development plus production) for the same time period would be about $100 million. The typical applications satellite might cost in the $40 to $60 million range, while the average advanced experiement might carry a $140 to $160 million price tag.

Integrating the data into the satellite servicing benefits equation yields the expression:

$$\begin{aligned} b &= [0.44 \times (2/7) \times (\$40+100M)] - C \\ &= \$17.6 \text{ million} - c. \end{aligned}$$

The average value of a servicing mission during the Space Station era, according to this calculation, is $17.6 million, minus the cost of the servicing mission. Using the satellite servicing mission costs presented earlier (and described more thoroughly in the following chapter), we arrive at a net economic benefit of:

$17.6 million-$5 million = $12.6 million

for a TMS mission, and

$17.6 million-$11 million = $6.6 million

for an OTV mission.

[4]Shockey, Edward F., "A Study of the Longevity and Operational Reliability of Goddard Spacecraft - 1960-1980," NASA Techncial Memorandum TM-82178: Goddard Space Flight Center, August 1981.

As evident from the cost data presented in Table 2-7, the key difference between TMS and OTV servicing costs is the cost of propellants. It is assumed that both TMS and OTV propellants will be recovered from the Shuttle or delivered to LEO by dedicated tanker, at a cost per pound of $500. The TMS, however, requires an average of only 1500 pounds of propellant, based on an average servicing payload of 5700 pounds and servicing altitude of 300 miles, while the OTV uses 12,000 pounds of propellants for its typical geosynchronous servicing mission. Since the vast majority of science and applications payloads will be serviced by the TMS, however, the OTV servicing costs are less significant. Based on our estimate (*see Section 2.3.3) that 90% of servicing missions will be performed by the TMS, and 10% by OTV, then the average benefit of a servicing mission is projected to be:

0.9 x $12.6 million +0.1 x $6.6 million = $12.0 million.

2.3.3 SATELLITE SERVICING BENEFITS ANALYSIS. Assessing the potential economic benefits of satellite servicing is complicated by uncertainty over the number of servicing missions that will be performed. For the space-based OTV function, considerable data are available regarding satellite launch requirements, which provide a sound basis for development of an OTV mission model. The satellite servicing function, however, represents a new use of space, rather than an improved method of performing current space activities, so its level of use is more difficult to estimate.

The mission models developed for this study reflect more about what is not known about satellite servicing requirements than what is actually known. Since we do not yet know which of the proposed satellites and experiments will ultimately be operational by the 1990s, nor how frequently they will require servicing, it is difficult to accurately predict servicing requirements. We expect relatively few OTV servicing missions, due to the factors discussed earlier in this section, and hence a fairly high reliance on the TMS for servicing.

Our mission requirements data suggest an average of seven planned servicing missions per year during the 1990s, including an average of one OTV servicing mission and six TMS missions annually. Our mission requirements data are not particularly helpful in predicting unplanned servicing requirements, since payload planners are reluctant to plan for malfunctions. Of the 57 satellites studied by NASA for operational reliability (see Section 2.3.2), malfunctions of significant mission criticality (m > 0.10) occurred an average of 26 times per year.[5] This would represent a high satellite servicing rate for unplanned Space Station era servicing missions, since the tendency through the 1990s will probably be to rely on small numbers of large and complex satellites rather than large numbers of small ones. Half the GSFC total, or about 13 missions per year, is our conservative baseline estimate of 1990s unplanned servicing requirements, including 12 TMS missions and 1 OTV mission per year. This is roughly consistent with repair and servicing data from Skylab missions, which show unplanned servicing tasks to be about twice as frequent as planned maintenance.

[5]See footnote 1.

Total satellite servicing requirements come to an average of 20 missions per year, including 18 with the TMS and 2 via OTV. By setting a high mission model case at 30 servicing missions per year and a low estimate at 10 per year, and assigning high and low values to the other satellite servicing variables, we can set up a table of key assumptions to be used in the satellite servicing benenfits analysis (see Table 2-15).

Table 2-15. Satellite Servicing Benefits Analysis: Key Assumptions (1984 $)

Variable	Low Value	High Value	Assumed Value	Variable Code
Mission Criticality Factor	0.2	0.6	0.44	m
Life Extension Factor	1	4	2	e
Design Life	3	10	7	d
Launch Cost	$25M	$75M	$40M	l
Unit Cost	$50M	$150M	$100M	u
Cost of Servicing Mission	$3M	$10M	$5.6M	c
Number of Servicing Missions/Yr	10	30	20	n

When modified to calculate annual economic benefits as a function of these variables, the satellite servicing benefit equation becomes

$$B = n \times [(m \times e/d \times (l+u)) - c]$$

where B is the annual economic benefit of satellite servicing. With all variables set at their baseline values, the expected annual value of satellite servicing becomes:

$$B = 20 \times [(0.44 \times 2/7 \times (\$40\text{ M} + \$100\text{M})) - \$5.6\text{M}]$$

$$= 20 \times \$12\text{M} = \$240 \text{ million}$$

It can be seen that the $12 million benefit per mission in this equation corresponds with the average benefit per mission derived earlier in Section 2.3.2. This worked out because the assumed average cost of a servicing mission, $5.6 million, is based on the same breakdown between TMS and OTV missions (i.e., 90% and 10%, respectively) used previously.

2.3.3.1 Sensitivity Analysis. The sensitivities of satellite servicing benefits to the variables in Table 2-15 are illustrated in Figure 2-14 and 2-15. Economic benefits are most sensitive to the effectiveness of the servicing missions in enhancing the satellite's capabilities (mission criticality factor, Figure 2-14a) and life extension factor (Figure 2-14b),

and to the design life of the satellite (Figure 2-14c). Benefits are not quite as sensitive to, but are still strongly influenced by the unit cost of the serviced satellite (Figure 2-15b) and the number of servicing missions performed (Figure 2-15d), and are moderately sensitive to the satellite's initial launch cost (Figure 2-15a) and the average cost of the servicing missions (Figure 2-15c). These sensitivities are summarized in Table 2-16.

2.3.3.2 <u>Summary of Satellite Servicing Economic Benefits</u>. The potential economic benefits of satellite servicing are not as great as the potential value of providing launch services via space-based OTV, but are nonetheless significant. These benefits are summarized in Figure 2-16. A nominal servicing benefit of $240 million per year represents about 15% of the total expected economic value of the Space Station, and these benefits could increase substantially if satellites are designed to maximize the advantages of Space Station servicing capabilites. Potential benefits of reduced spacecraft design costs due to the availability of servicing have also been omitted from this analysis, since they are very difficult to predict.

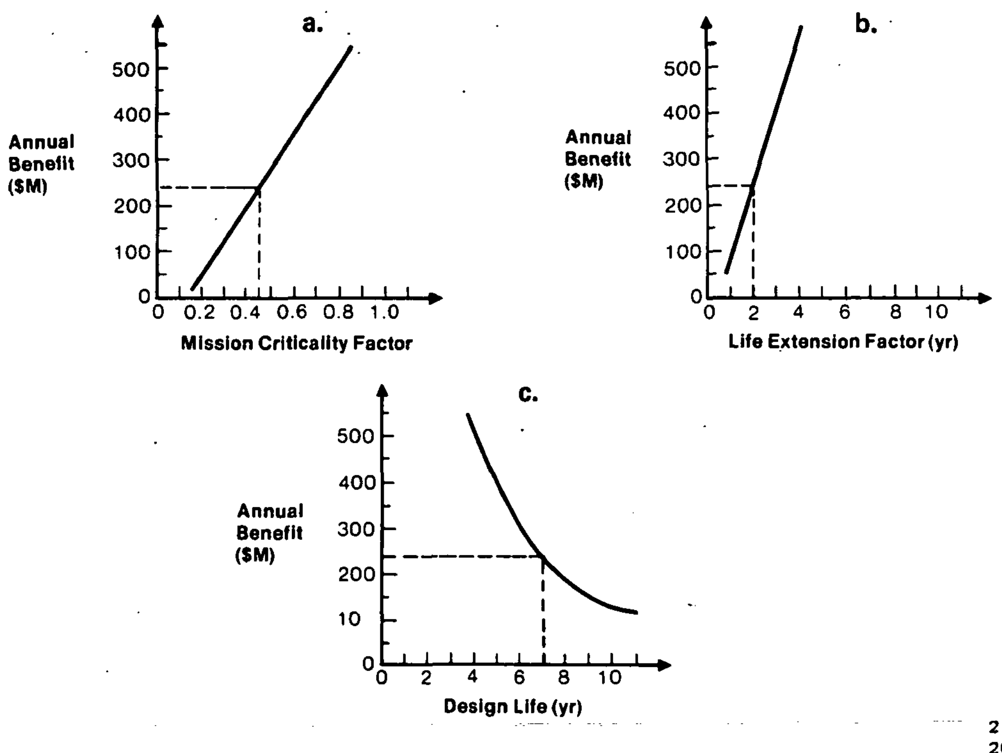

Figure 2-14. Satellite Servicing Sensitivity Analysis: Mission Criticality and Satellite Lifetime Factors (1984 $)

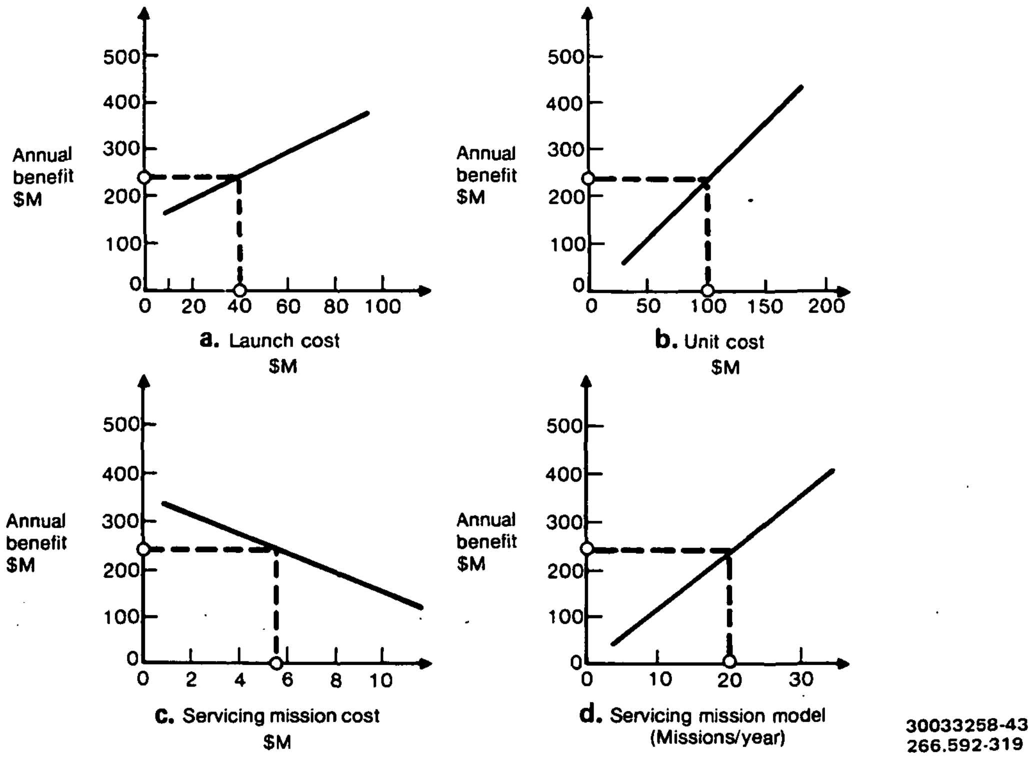

Figure 2-15. Satellite Servicing Sensitivity Analysis: Cost and Mission Model Factors (1984 $)

Table 2-16. Space Station Economics Benefits: Satellite Servicing Sensitivity Analysis (1984 $)

VARIABLE	LOW VALUE	HIGH VALUE	EXPECTED VALUE	WORST-CASE BENEFIT	BEST-CASE BENEFIT	SENSITIVITY
MISSION CRITICALITY FACTOR	0.2	0.6	0.44	$ 48M	$368M	HIGH
LIFE EXTENSION FACTOR	1	4	2	$ 64M	$592M	HIGH
DESIGN LIFE	3	10	7	$134M	$709M	HIGH
LAUNCH COST	$25M	$ 75M	$ 40M	$202M	$328M	MODERATE
UNIT COST	$50M	$150M	$100M	$114M	$366M	HIGH
COST OF SERVICING MISSION	$ 3M	$ 10M	$5 -6M	$152M	$292M	MODERATE
NUMBER OF SERVICING MISSIONS/YR	10	30	20	$120M	$360M	HIGH

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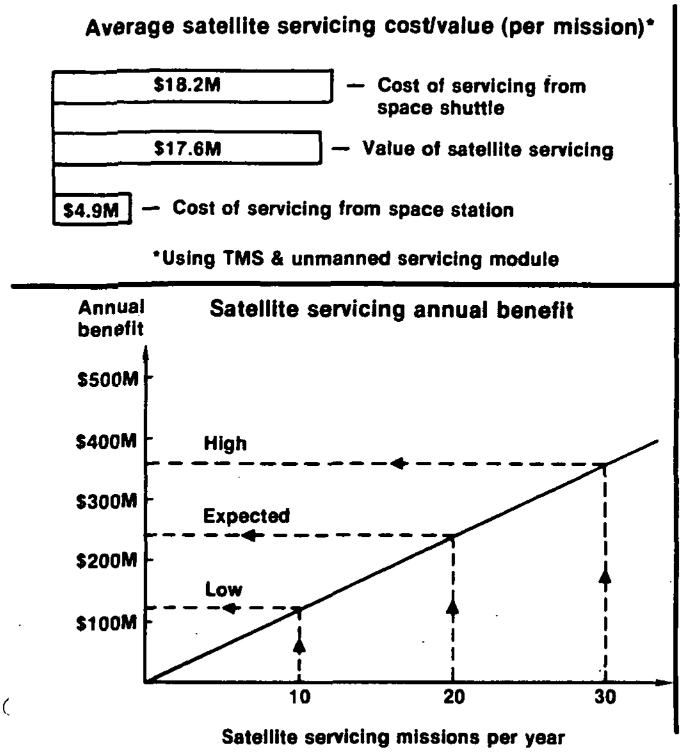
These satellite servicing benefits appear highly sensitive to many of the variables used in this analysis, and hence should be regarded as preliminary. Owing to these sensitivities, the unpredictability of these variables, and the difficulty in quantifying the economic benefits of servicing, further study is required to determined whether Space Station satellite servicing can be economically viable. A worst-case analysis with all variables set at their worst-cost levels results in a net loss in satellite servicing of $8.5 million per servicing mission.



Space Station Satellite Servicing

- Satellite servicing from space station expected to cost 75% less than servicing from space shuttle
- Results of satellite servicing (per mission, average)
  - From shuttle: $600,000 <u>loss</u>
  - From space station: $12 million <u>benefit</u>
- Expected annual benefit: $240 million
- Significant parameters
  - Satellite capabilities restored by servicing
  - Value of satellite
  - Satellite servicing mission model

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Figure 2-16. Economic Benefits: Satellite Servicing

Conversely, satellite servicing could turn out to be far more profitable than indicated in this analysis. Of particular concern is the average satellite unit value, which for the purposes of this study was estimated at $100 million. Since the current trend seems to be toward development of extremely large and sophisticated experimental facilities, such as the billion-dollar space telescope, the typical Space Station era asset might in fact have a much higher value. This would greatly enhance the cost effectiveness of servicing both from the Shuttle and the Space Station.

With potential economic benefits in the hundreds of millions of dollars annually, plus other benefits that are difficult to quantify in economic terms, satellite servicing shows promise as a valuable Space Station function. Determination of whether this function will be justifiable, and whether this justification will be based on an economic or noneconomic basis, requires further study.

2.4 RESEARCH AND PRODUCTION

2.4.1 <u>OVERVIEW OF RESEARCH AND PRODUCTION BENEFITS</u>. One of the great paradoxes of Space Station economics is that the Space Station function that is perceived to hold the greatest promise for long-term economic benefits is also the most difficult to fit into an economic model. This is the role of the Space Station in research and production, those activities that are carried out by the Space Station crew on board the facility.

The Space Station functions discussed in the two previous sections, OTV launch operations and satellite servicing, both involve the transportation and operation of existing or planned space assets. These assets, such as communications satellites and space-based observatories, have quantifiable economic values, based on either their revenue potential or cost. As a transportation and servicing nodal point, the Space Station has a clear role in enhancing the ability of these assets to achieve their mission objectives, through improvement of performance and/or reduction of costs, and many of these benefits are quantifiable.

The research and production function, however, is more difficult to evaluate. As a research facility, the Space Station will almost certainly yield economic benefits through the enhancement of our understanding of how the space environment affects both living systems and the man-made systems that we as humans can operate in space. As a production facility, the Space Station will ultimately lead to the establishment of factories and construction facilities in space, whose products will provide economic and social benefits for many people. Taken together, these research and production activities represent the true beginnings of space industrialization. Modeling the economic benefits of space industrialization today, however, is analogous to having asked King George II of England in 1776 to predict the future $2 trillion GNP of his rebellious American colonies.

Research and production in space will provide economic benefits long before the establishment of multibillion dollar space factories, but it is important to keep in mind that this Space Station function may have a much longer economic payback horizon (see Section 3) than the other Space Station functions. The near-term economic benefits of research and production will most likely be in the form of cost savings for science and applications users who would otherwise depend on Space Shuttle accommodations, and for commercial users who would use the Space Station as a "test bed" for development of new products and services.

The nature of Space Station research and production benefits raises a key issue in Space Station planning. For a variety of reasons, general thinking has been that the research and production function would dominate early Space station activities. The most direct explanation for this is that in a budget-constrained evolutionary Space Station program scenario, the research and production capability requires the least development time, and at a lower cost than the other Space Station functions. Despite their near-term economic potential, OTV operations and satellite servicing have traditionally been viewed as later, lower-priority Space Station developments due to their technological complexity and expense.

As long as Space Station planning criteria have focused on achievability and cost, this viewpoint has endured. But with the recent emphasis on commercial involvement and economic return, Space Station supply and demand expectations have diverged. The near-term economic advantages of the OTV and satellite servicing are now very much in demand, because they relate well to the current, payback-oriented Space Station program orientation. But the supply side budget constraints remain, so the research and production function remains attractive as an initial Space Station capability. For these reasons, it is important to at least attempt an evaluation of near-term research and production benefits.

2.4.2 RESEARCH AND PRODUCTION BENEFITS TO COMMERICAL USERS. As evident from Sections 2.3 and 2.4, the commercial user group most likely to benefit from the Space Station is the communications satellite industry. Since space communications is now the only mature commercial industry in space, this is not an unexpected conclusion. The communications industry should benefit economically from the research and production function, as well as the OTV and satellite servicing activities.

One immediate potential benefit to the communications industry is in the use of the Space Station for testing and checkout of satellites prior to transfer to geosynchronous orbit. This capability is present to some degree with the Space Shuttle, but certainly not to the extent possible on a manned Space Station. A much wider variety of test equipment could be made available on the Space Station, and crew members would have greater access to, and more time to inspect the payload. Most important, the satellite could be repaired on board the Space Station, rather than having to be returned to Earth. In addition to the launch cost savings of having LEO repair capability, two less obvious economic benefits could accrue from this LEO checkout capability.

The first of these is insurance. Communications satellites are typically insured against revenue loss from operating failure, at a rate of 1 to 2% of stated value per year. For a 24-channel satellite that rents for $6 to 8 million per month, the insurance premium could be as high as $120 to $160 thousand per month, or $1.4 to $1.9 million per year. Predeployment checkout in LEO could diminish the risk of spacecraft failure, and hence result in lower insurance premiums. A reduction in premium rates of only 10% would result in a savings of up to $140,000 to $190,000 per satellite per year in insurance costs, with potentially greater benefits for larger satellites.

A second potential economic benefit of LEO checkout is reduction in spacecraft redundancy. About 8 to 10% of communications satellite nonfuel and nonstructural weight is for redundant systems, which add about $3 million to satellite cost.[6] If the availability of satellite checkout at the Space Station could significantly reduce the amount of redundancy required on communications spacecraft, a potential savings in the hundreds of thousands of dollars per unit could be realized.

The research and production function of the Space Station will also provide economic benefits to commercial communications users through technology development activities. These will lead to the development of such systems as large deployable antennas and laser communications, with immediate applications in areas such as Land Mobile Satellite Service, Direct Broadcast Satellites, and RFI measurements. On the longer term horizon, a Space Station could play a key role in the development of large communications platforms, whose potential applications include futuristic communications devices such as wristwatch telephones. The potential economic benefits of these developments are impossible to calculate, but could easily be in the billions of dollars.

[6]Spacecom, "Space Station Study-Needs, Attributes and Architectural Options: Commercial Communications Satellies," Final Subcontract Report to General Dynamics, February 1983.

A wristwatch telephone concept cited by The Aerospace Corp. nearly a decade ago, for example, would serve 25 million users. Based on a user charge of $50 per month, this represents a total market potential of 25 million x 12 x $50 = $15 billion per year. The cost of such a program was estimated at about $4.3 billion (1984$).[7]

A second commercial benefit from the Space Station research and production function will be in the emerging field of materials processing in space (MPS). Commerical interest in MPS to date has been limited by lack of long-term access to the space environment and excessive space transportation costs, but the Space Shuttle is expected to provide an interim solution to both of these problems. The long-term growth of commerical MPS, however, can be accomplished only by the establishment of permanent space facilities such as the Space Station and free-flying platforms.

Up until now, the total time of MPS experimentation performed in space by the U.S. numbers fewer than 100 hours. Consequently, MPS remains an infant science, and no commerically viable space processes have been positively identified. It is known that zero gravity has potential benefits in the production of biological materials, crystals, alloys, and ceramics, but our experience with such phenomena is limited. The Space Shuttle, particularly in its Spacelab mission role, will provide a much needed opportunity to carry out the basic research necessary for the identification of commercial opportunities in MPS.

Owing to limitations on Shuttle performance, however, particularly with regard to power availability and mission duration, the maturation of MPS as a science and an industry may ultimately depend on Space Station research and production capabilities. Pharmaceutical materials appear to be the most likely candidates for near-term commercial space processing, with a McDonnell-Douglas/Johnson & Johnson joint-endeavor with NASA aiming at commercial production by the late 1980s.[8] It is important to note that all participants in this project consider the establishment of free-flyers to be a prerequisite for the commercial success of the venture. If this program is successful, deployment of commercial MPS free-flying platforms may actually precede establishment of the Space Station.

When the Space Station becomes available, servicing and maintenance of such MPS free-flyers may be accomplished more efficiently and cheaply than with the Shuttle. The basis for these improvements was discussed in the section of this report dealing with satellite servicing benefits. As pointed out in that section, however, the Space Station may not offer much benefit in the transport of materials between Earth and the free-flyers. Since Shuttle flights

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[7]The Aerospace Corporation, "Study of the Commonality of Space Vehicle Applications to Future National Needs," NASA Contract NASW-2727, 24 March 1975.

[8]Agreement between the National Aeronautics and Space Administration and the McDonnell Douglas Astronautics Company for a Joint-Endeavor in Materials Processing in Space, January 1980.

will be required for delivery of raw materials to LEO and return of finished products to Earth, it may be more practical to perform this operation directly, without involvement of the Space Station. One exception (as discussed previously) would be if Shuttle costs could be reduced by transporting the materials in small lightweight containers, which can be replaced with the production cannisters at the Space Station.

The greatest performance benefit of the Space Shuttle for MPS will be in those processes requiring or benefiting from manned interaction. This will almost certainly represent a benefit in the precommercial development phase of MPS activities, where man's role in observing and modifying new processes will be valuable. For commercial processes, however, automation may serve effectively in many cases. These trade-offs between manned interaction and automation are difficult to perform now, since we do not yet know which processes will be shown to be commercially viable. Hence, we will be in a much better position to assess the economic benefits of a Space Station for commercial MPS in a few years, when we are closer to understanding which MPS activities have commercial potential.

Aside from communications and materials processing, the Space Station research and production function may ultimately benefit commercial applications of technology development activities in such areas as energy conversion and transmission. These technologies are so far from commercialization, however, that it is too early to evaluate the economic benefits of the Space Station in such endeavors. Other commercial pportunities in such areas as acquisition and processing of nonterrestrial materials may also evolve from Space Station research and production, but these activities are beyond the scope of this study. In planning a Space Station for the 1990s, however, these possibilities should be considered, to maximize Space Station utilization options for the post-2000 time period.

2.4.3 RESEARCH AND PRODUCTION BENEFITS TO SCIENCE AND APPLICATIONS USERS. Although the commercial benefits of Space Station research and production are difficult to evaluate, the science and applications activities that will precede commercial production do promise some quantifiable benefits. In materials processing, for example, even though no commercial processes have yet been identified, we can be reasonably certain that precommercial research will benefit from Space Station improvements in manned interaction, power availability, and mission duration.

Our approach to evaluate Space Station benefits in MPS was to derive a special function that describes certain mission capabilities and their related costs. One interesting approach is to calculate the "cost per kilogram-hour" of Space Station MPS accommodations. The cost/kg-hr would equal:

$$\frac{\text{Total Cost}}{\text{Number of hours}} \times \frac{1}{\text{Number of kg}}$$

for the various mission alternatives for MPS. By using the maximum number of hours and kilograms of weight capability available with any given system, we can determine the minimum cost/kg-hr for these alternatives. The cost/kg-hr provides a means of assessing the costs of space processing based on two of the most critical attributes required for MPS: weight capability in orbit and mission duration.

Table 2-17 shows the costs, mission duration, and payload capabilities of various systems, ranging from the SPAR Rocket to a two-year Space Station processing capability. Cost/kg-hr declines dramatically as mission capabilities improve, even though in the Space Station cases general housekeeping costs have been added to transportation costs. These housekeeping costs have been estimated at $100,000 per day; this corresponds to one man-day of support for a processing facility at $10,00/hr, or $80,000/day, plus a 25% contingency charge.

Table 2-17. Cost/kg-hr for MPS (1984 $)

	Mission Capability		Cost			
	Hours	kg	Transportation ($M)	Housekeeping ($M)	Total ($M)	Cost kg-hr ($)
SPAR Rocket	0.083	454	500,000	N/A	500,000	13,270
KC-135 Aircraft	0.014	7,600	6,000	N/A	6,000	56.80
Space Shuttle	168	19,500	83.3	N/A	83.3	16.80
Space Station (90-day)	2,160	14,125	53.1	9	62.1	2.04
Space Station (2-year)	17,520	14,125	127.4	73	200.4	.81

In the final case (Space Station two-year mission), periodic resupply missions are included in the transportation costs. Every 90 days, new raw materials are delivered to the Space Station via Shuttle for processing, and finished products are brought back to Earth on the return flight. As an initial estimate, each resupply mission is calculated to require delivery of 20% of the total MPS system weight to LEO. These additional transportation costs, however, are outweighed by the benefits of mission continuity over a two-year period. For two-year missions, the Space Station, at 81¢ per kilogram-hour, is over 20 times as cost effective as the Space Shuttle.

These economic benefits will certainly enhance commercial MPS opportunities, but since no commercially viable processes have been positively identified, the reduction in cost/kg-hr is presently accounted for as a benefit to science and applications users. Once commercial products with known values can be identified, the cost/kg-hr will have greater value as a measure of commercial MPS benefits.

The cost/kg-hr can also be used to quantify benefits to other science and applications users. Consider, for example, the Upper Atmosphere Research Payload, which can fly either in the Shuttle cargo bay or on a Space Station pallet. With a Shuttle charge factor of 0.11 (based on its 2-meter length), the 2500-pound payload would cost about $12 million to fly in the Shuttle, with a cost/kg-hr of $28.81. As illustrated in Table 2-18, the Space Station reduces this to $3.07/kg-hr for a 90-day mission, and $1.11/kg-hr for a two year mission, despite the very conservative assumption of $50,000/day in Space Station housekeeping costs for this payload.

Table 2-18. Cost/kg-hr for Upper Atmosphere Research (1984 $)

	Mission Capability		Cost			
	Hours	kg	Transportation ($M)	Housekeeping ($M)	Total ($M)	Cost/kg-hr ($)
Space Shuttle	168	25,500	12.1	N/A	12.1M	23.81
Space Station (90-day)	2,160	25,500	12.1	4.5	16.6M	3.07
Space Station (2-year)	17,520	25,500	12.1	36.5	48.6M	1.11

A more general way to assess Space Station research and production benefits in science and applications is to use the known costs of Spacelab as a basis for comparison. Table 2-19 shows the costs of a one-week Spacelab mission and compares them with estimates of the costs of using for one week a Spacelab-type module permanently docked to a Space Station. The key assumption in this analysis is that Space Shuttle transportation costs are reduced by permanently basing the Spacelab at the Space Station. Instead of launching the entire Spacelab module, only experiment racks are brought to LEO, in specially designed cargo bay structures or containers. These racks are then integrated with the Spacelab module in space. This would be more complex than payload integration on the ground and is accounted for in the 50% higher "Optional Services" cost for Space Station utilization. Transportation costs, however, are much lower; in this case it is assumed that only one-third of the Shuttle's capacity is required for delivery of the experiment racks to LEO. When contrasted with the requirement for a dedicated Shuttle flight (for Shuttle-Spacelab missions), this represents a cost saving of $46.6 million in space transportation charges. The net result is a 37%, $37 million benefit per one-week Spacelab mission.

It should be noted that the Space Station's capability for long duration missions is not reflected in this benefit. Even though the Space Station is cost effective for one-week missions, its most dramatic advantage is in performing, without resupply, missions that would require multiple Spacelab missions. This is the basis for the Space Station's order of magnitude improvement over the Space Shuttle in cost per kilogram-hour.

Table 2-19. Spacelab Accommodation Cost Comparison (1984 $)

	Transportation ($M)	P/L Integration ($M)	Housekeeping ($M)	Total ($M)
Space Shuttle	83.3	16.7	N/A	100
Space Station	36.7	25.0	1.4	63.1

Table 2-20 returns to the cost/kg-hr analysis in showing the large economic benefit of using the Space Station for 90-day science and applications missions. The only increase in cost over the one-week Space Station mission is in Housekeeping; this cost is assumed to be $200,000/day for two dedicated crew members. When used for one-week missions, the Space Station cost/kg-hr is 37% less expensive than the Shuttle-Spacelab, corresponding to the benefit shown in Table 2-20. When used for 90 days, however, this cost reduction increases to 94%, since at least 12 Shuttle flights would be required to achieve this mission duration. This represents a theoretical benefit of over $1 billion for one 90-day mission, but since the Shuttle would never be used in this manner, the previous analyses are more realistic indications of Space Station benefits.

Table 2-20. Cost/kg-hr for Spacelab-Equivalent Missions (1984 $)

	Mission Capability		Cost				
	Hours	kg	Transportation ($M)	Optional Services ($M)	Housekeeping ($M)	Total ($M)	Cost kg-hr ($)
Space Shuttle	168	29,500	83.3	16.7	N/A	100	20.18
Space Station - 1 week	168	29,500	36.7	25.0	1.41	63.1	12.73
Space Station - 90 days	2160	29,500	36.7	25.0	19.0	79.7	1.25

2.4.4 RESEARCH AND PRODUCTION BENEFITS ANALYSIS. Analysis of the economic benefits of Space Station research and production must proceed with the understanding that this is the Space Station function whose economic value is most difficult to quantify. As mentioned earlier, the theoretical economic value of research and production could exceed $1 billion per year by the 1990s, but the ultimate value of these activities is not likely to be reflected in material benefits until after the turn of the century. Until these long-term benefits are accrued, the research and production function should be recognized as that aspect of Space Station activity most devoted to the less tangible benefit of space development: advancement of knowledge.

The billion-dollar economic benefit figure, however, is arrived at rather simply. In order to perform 90 days worth of scientific research and development in space with the STS/Spacelab configuration, about 13 Shuttle flights would be required, based on the Shuttle's one-week limitation on orbital duration. At $100 million per Spacelab mission, the cost of this activity would be approximately $1.3 billion. The cost of 90 days of research on the Space Station, however, is estimated at about $80 million, a cost advantage of $1.2 billion over using the Shuttle/Spacelab.

As already point out, this analysis lacks realism in that the Shuttle and Spacelab would never be used 13 times a year, much less within a 90-day period. The Spacelab was originally envisioned for use 10 times per year, but a more realistic projection of Spacelab utilization is about half this total. This presents a more moderate view of Space Station research and production benefits, as illustrated in Table 2-21. Based on the costs developed earlier for one week-equivalent Spacelab missions, the annual benefit of the Space Station over Spacelab is about $185 million.

This represents a conservative approximation of the Space Station economic advantage over Spacelab, since the $315 million Space Station cost estimate includes five separate Shuttle missions to the Space Station for experiment changes and resupply. If the experiments for five Spacelab-equivalent missions could be delivered to the Space Station laboratories on a single Shuttle mission, the total cost of performing the missions could decline by up to $200 million, resulting in a net benefit of $185 million + $200 million = $385 million. This additional benefit is arrived at in the following manner:

Cost of five partial Shuttle missions for Space Station experiment resupply:

  5 x $36.7 million = $183.5 million (transportation)
+ 5 x $25.0 million = $125.0 million (payload integration)

= $308.5 million

Table 2-21. Research and Production Annual Benefits

	Mission Cost ($M)	Misson Rate	Annual Cost ($M)
Space Shuttle/Spacelab	100	5/yr	500
Space Station	63.1	5/yr	315

Cost of one dedicated Shuttle mission for Space Station experiment resupply:

  1 x $83.3 million = $83.3 million (transportation)
+ 1 x $25.0 million = $25.0 million (payload integration)

= $108.3 million

Additional benefit of Space Station based on lower resupply requirement:

$$\begin{array}{r} \$308.5 \text{ million} \\ - \underline{\ 108.3 \text{ million}} \\ = \$200.3 \text{ million} \end{array}$$

The actual benefit would probably fall somewhere between $185 million and $385 million, since the number of Shuttle resupply missions required for Space Station resupply (in support of five Spacelab-equivalent missions) would probably be greater than one and fewer than five. A median baseline estimate of Space Station economic benefits in improvement in Spacelab efficiency is then:

($385 million + $185 million)/2 = $285 million

2.4.5 RESEARCH AND PRODUCTION ECONOMICS BENEFITS SUMMARY. The benefits for this area of analysis are summarized in Figure 2-17.

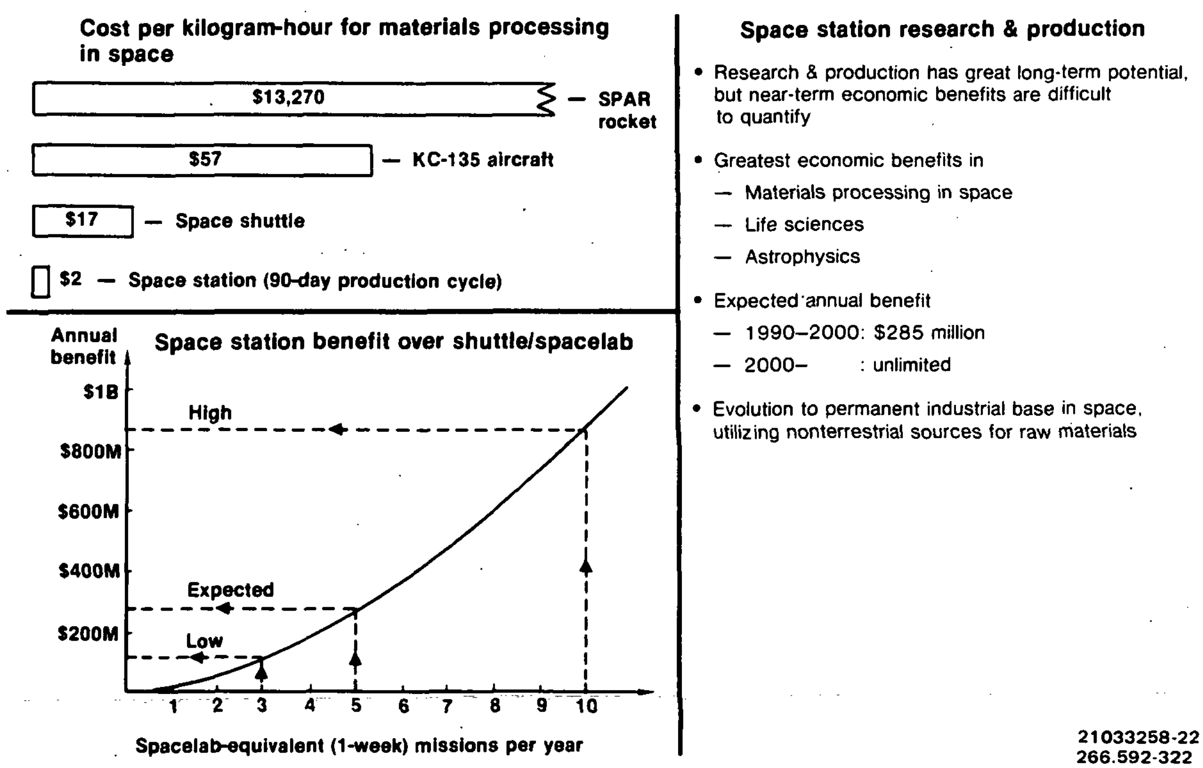

Figure 2-17. Economic Benefits: Research and Production

2.4.6 A BROADER PERSPECTIVE ON ECONOMIC BENEFITS. While a baseline economic benefit of $285 million is reasonable estimate of the Space Station's cost advantage over other means of performing similar research and production activities (i.e; Spacelab), it should be viewed only as that part of the near-term economic benefit that is quantifiable. In both the near and long term, the Space Station should have two classes of research and production benefits whose economic impact are impossible to quantify at the present. One type of benefit will be improvements in the cost effectiveness of performing scientific research and technology development in space, which are not accounted for in the Spacelab mission-equivalent cost comparison. These will result primarily from the ability of the Space Station to support scientific missions of greater duration and complexity than could be accomplished without a Space Station. Although economic returns are likely to accrue from these advantages, such advancements are more accurately characterized as performance benefits, and are not appropriate for detailed analysis in this economic volume. The other type of economic benefit that cannot yet be assigned a dollar value is related to the role of the Space Station in creating new goods and services. The two disciplines that should contribute most heavily to the development of new space processes and products are life sciences and materials processing in space. By providing an opportunity to study the long-term effects of the space environment on living systems and physical processes, with a high degree of manned interaction, the Space Station may lead to the discovery of many ways in which living and working in space can materially benefit mankind.

In the area of life sciences, many of the benefits will be related to the enhancement of human performance in space, but applications in the advancement of earth medicine appear possible. By observing the effects of zero-gravity on the human skeletal, vestibular, and cardiovascular systems, we may find ways to improve our treatment of people of earth who have medical problems related to these areas. Any significant improvements in the field of medicine are likely to have considerable economic benefits.

In materials processing in space, the potential exists for the creation of high-value products in space that cannot be produced under Earth-normal gravity conditions. As discussed earlier in this section, MPS appears to have its greatest potential in the production of biological and electronics materials, although other applications have promise as well. The market for space-processed pharmaceuticals has been estimated at up to $6 billion annually by the early 1990s. Such products could provide social and economic benefits in the treatment of kidney disease, dwarfism, diabetes, and many other ailments.

Although the current emphasis appears to be on near-term economic benefits in areas such as life sciences and MPS, the ultimate economic value of space research and production will not be realized until well beyond the 1990s. There is literally not a single long-term use of space that could not benefit in some manner from the existence of a Space Station in low earth-orbit, and the potential economic value of these longer-term developments is unlimited. The Space Station could play a pivotal role in the development of a vast space manufacturing system utilizing lunar and asteroidal resources and producing such outputs as solar power satellites and permanent space settlements. A space manufacturing system spanning the Earth-moon system and making use of unique space resources (Figure 2-18) could be established in as few as 15 years, and might be financed largely from revenue generated by the Space Station during the 1990s.

Establishment of a space manufacturing system may be beyond the scope of this study, but a 1990s Space Station should be designed with such future developments taken into consideration. The economic value of a Space Station must also be taken to include these types of activities, although their dollar value is difficult to predict. The Space Station, like the Space Shuttle, should be viewed not as an end in itself, but as a means to opening up the frontier of space for uses that have significant social and economic benefits for mankind.

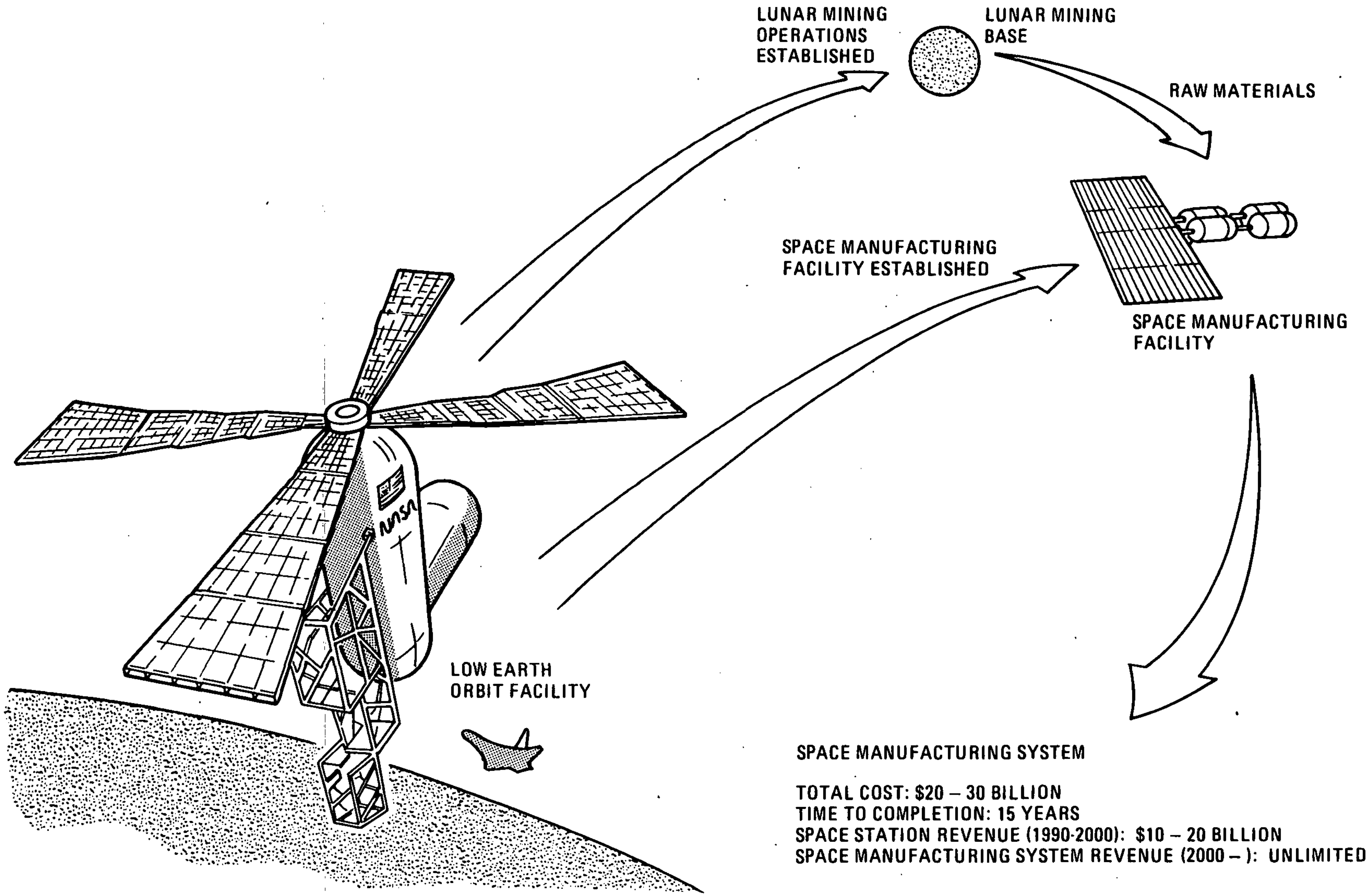

Figure 2-18. The Space Station Could Play a Pivotal Role in the Development of a Space Manufacturing System Which Would Establish a Permanent Industrial Base in Space, Based on the Utilization of Nonterrestrial Materials

SECTION 3

PROGRAM COST ESTIMATES

This section documents the analysis conducted to determine the cost of the Space Station program options investigated. An overview of this task is shown in Figure 3-1. The subsequent discussion includes the general methodology, development, production, and operations cost estimates and annual program funding requirements.

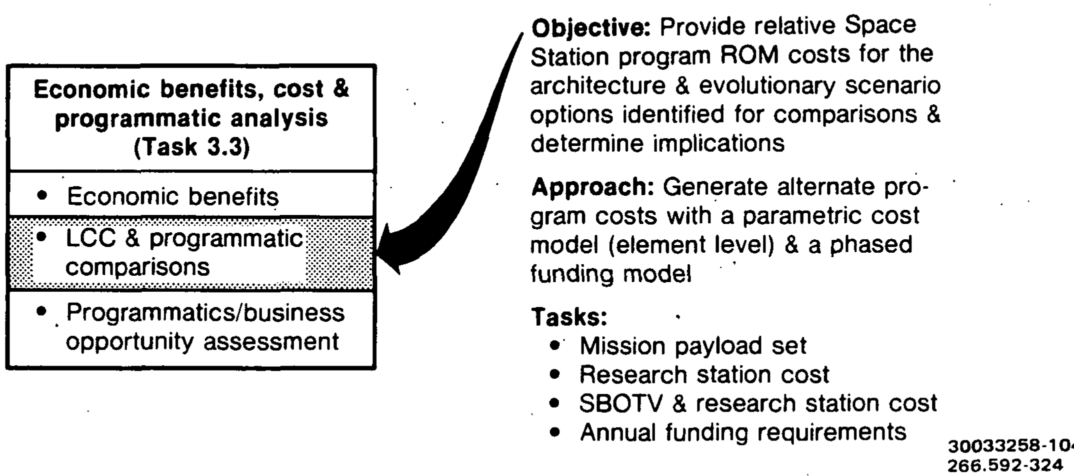

Figure 3-1. LCC and Programmatic Comparisons

3.1 GENERAL METHODOLOGY

The conceptual phase of program development requires that total system cost be determined in an expedient and timely manner for trade studies and for concept evaluation and selection. It is seldom possible from the standpoint of either cost or time to engage in the detailed cost-estimation process used to establish firm program bid estimates. This detailed approach is prohibitive primarily because of the many concept variations to be estimated and the limited time available for the estimates themselves. A parametric cost model is therefore generally used to develop cost data in an efficient manner, yet with acceptable overall accuracy and realism representative of the program under study. It was decided at the outset of the Space Station study that a model, developed specifically for this type of vehicle, would be used throughout the study as the basic tool for generating Space Station system costs. This model provides the principal framework for the final cost estimates of the baseline and options and is supplemented by point estimates, where available (Table 3-1).

Table 3-1. Space Station Program Cost Estimates

Approach

- Determine relative program ROM LCC costs for the defined options of:
  - Architecture (hardware)
  - Evolutionary scenarios (programmatic)
- Including:
  - Space stations & mission equipment
  - Free-flyers/platforms & their mission equipment
  - Transportation system
- And use annual funding requirements as a measure of program reasonableness

Methodology

- Use a cost model tailored to the module level to estimate LCC (RDT&E, production & operations) & annual funding requirements
- Calibrate to JSC SOC, Boeing SOC, McDonnell Douglas MSP, etc.

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3.1.1 PARAMETRIC COST MODEL. The principal tool for generating cost information for trade studies during the study and for the final project cost estimate is a parametric cost model. This cost model, developed specifically for large spacecraft vehicles, generates cost parametrically at the subsystem level, from vehicle and program definition input data. For the final project cost estimate, the model accepts direct inputs of point estimates at the desired level of detail as may be available.

This cost analysis approach is illustrated in Figure 3-2. The Space Station system work breakdown structure (WBS) provides the overall cost format and is used as a basis to identify cost elements to cover all costs expected to be incurred during the program. The WBS also sets the requirements for cost estimating relationships (CERs), cost factors, or point estimates. These CERs are then derived, based on an analysis of historical cost data and an analysis of cost driving parameters, for the range of technical approaches and performance parameters encountered in the program.

The model itself first derives a unit hardware cost or first unit cost. This unit hardware cost is then employed where necessary during the derivation of nonrecurring (development) costs and recurring (production and operation) costs. These are then accumulated as desired to provide the required total program cost and the required levels of summarization.

Nonrecurring, or development, cost consists of the one-time cost of designing, developing, testing, and evaluating an end item. Specifically, it includes development engineering and development support (design and analysis), test hardware, ground testing and evaluation, ground and flight support equipment (GSE and FSE), tooling and special test equipment, facilities and facility activation, and other program peculiar costs not associated with production. It includes all the elements of cost (resources) such as labor (engineering, production, tooling, etc.), materials, subcontracts, general and administrative (G&A) expenses as well as the subdivision of effort such as management, design and tooling production necessary for the development of the program.

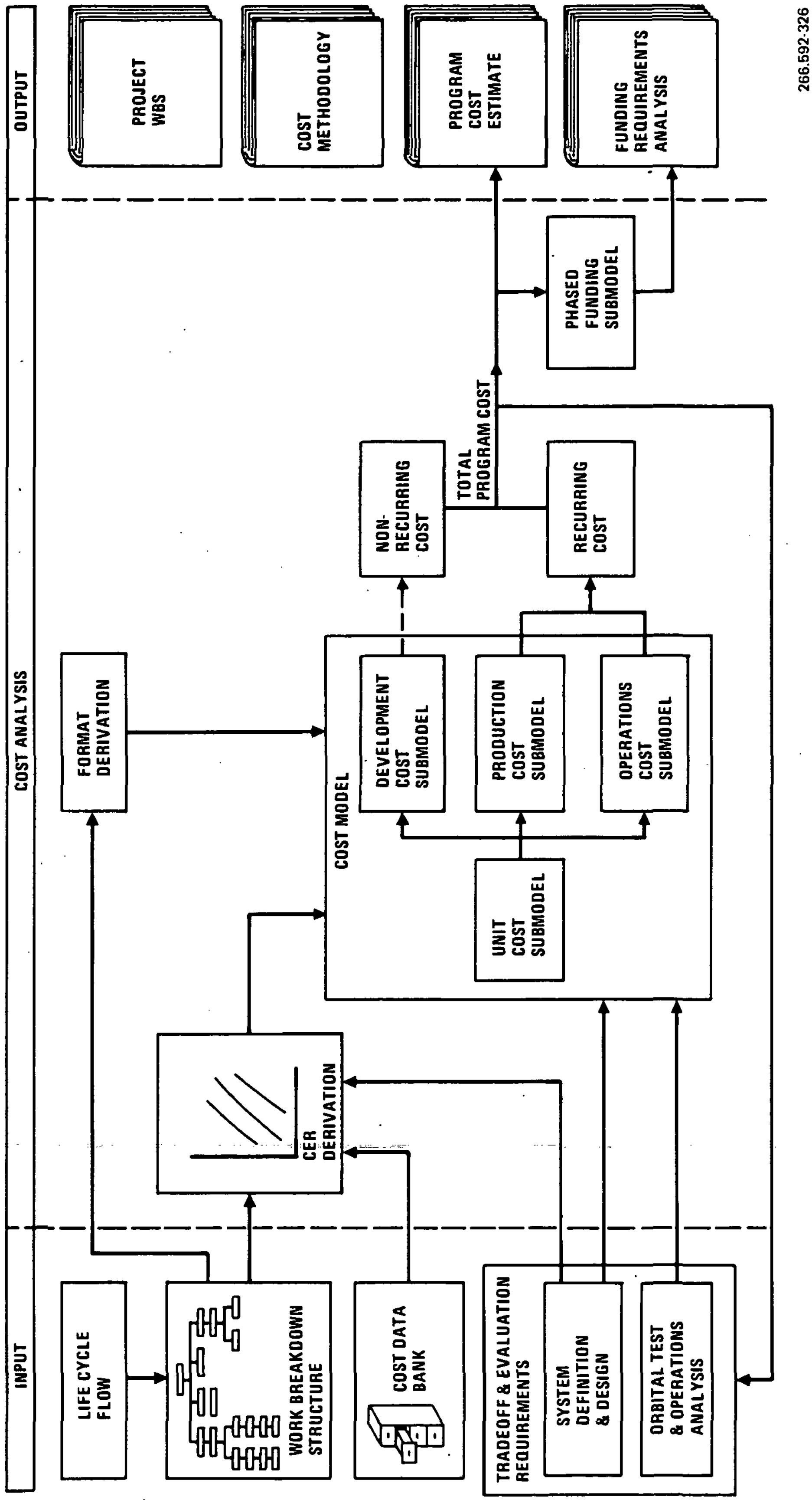

Figure 3-2. Cost Analyses Study Flow

The recurring production category includes the costs associated with the production of all flight hardware articles through acceptance of the hardware by the customer, including all costs associated with the fabrication, assembly, ground test, and checkout of flight articles, as well as associated sustaining engineering and tool sustaining and maintenance. As discussed above, this category includes all elements of cost and subdivisions of work necessary for production of these articles.

Recurring operations includes the costs incurred after customer acceptance and for the remaining life of the system. It includes the ground operations and integraton preceding launch, flight operations, and mission operations during the operating life of the system or the specified time period. It also includes all maintenance and refurbishment hardware, including update or replacement equipment.

CERs or cost factors are derived for each of the cost elements by the following approach. A survey and collection of available cost and technical data is undertaken from available sources, including historical hardware program costs, study programs, and available detailed estimates. The data obtained are then subjected to a thorough analysis to determine validity and confidence level, and are normalized to standard ground rules to provide for varying raw data inclusions and exclusions and for inflation effects. The data are then analyzed to establish technological families (groupings of subsystems based on hardware type, complexity, and state of the art) and to select an appropriate parameter (performance or sizing) that shows good correlation with cost for use as a driver in a relationship for cost prediction of new systems. Valid high confidence data-point families resulting from this anlysis are used to derive the cost relationship equation from a graphical presentation of these data points using standard regressing curve fitting techniques.

The high degree of commonality necessitates the use of development factors for the appropriate adjustment of the CERs to obtain a proper relation to the historical data from which it was derived. The factor includes: 1) an assessment of design complexity, 2) a commonality factor to establish the previous applicable development, and 3) the degree of new development required, which relates to component availability (off-the-shelf, etc.). Recurring production hardware CERs also require a complexity factor associated with type of materials, technology, or manufacturing methods to provide for a proper relation to available historical data.

Point estimates used in the final cost estimate in certain cases are generally estimated in greater detail, Level 6 (assembly level) or Level 7 (component level). These are determined by either a detailed estimating approach or a more summary method, including comparative techniques with current ongoing hardware or study programs, analysis of historical costs, and vendor estimates.

3.1.2 COST ANALYSIS GROUND RULES. The following is a listing of the ground rules and assumptions that were followed in estimating the Space Station system costs reported herein.

a. Costs are estimated in constant FY 1984 dollars.

b. This study is a requirements and architectural study and not a configuration study.

c. The Space Station life cycle cost (LCC) estimates are therefore very rough order of magnitude (ROM) and are intended for option comparisons only.

d. The Space Station LCC estimates are generated from a parametric model using generic very ROM input.

e. The economic benefits analysis will be conducted parametrically.

f. Costs are estimated for the entire Space Station architecture including government costs.

g. Annual funding requirements are provided both for specific elements as well as the total NASA budget level.

3.2 PROGRAM DESCRIPTIONS.

Because the objective of this study is to primarily address the architecture and evolution of a Space Station program, only a minimum amount of configuration detail has been generated. The definitive data that were generated to permit ROM cost estimates to be generated for program comparisons are therefore of a highly generic nature. This section presents the program descriptions for those options studied. It includes the WBS identified mission payloads and a description of the station elements, architecture, and evolutionary options.

3.2.1 WORK BREAKDOWN STRUCTURE. The WBS is a comprehensive breakdown of all total program life cycle elements categorized or sorted into several levels of hardware and task or function-oriented end items. The WBS serves to identify all of the cost elements to be included in the cost analysis task. This WBS contains all of the hardware and tasks associated with Phase C/D development and test, fabrication of the flight hardware, and the activities incurred during the placement flight, servicing flights, and mission operations. It serves as the basic format for cost reporting and programmatic data.

The WBS used for the Space Station elements is based on the infrastructure shown in Figure 3-3. These WBS elements and their structure are designed to be applicable to each of the major phases of the program, namely, development, production, and operations. Because some of the WBS elements are obviously not applicable to all of the phases, zero costs are incurred for such elements and the element is ignored as costs are subsequently recorded and accumulated.

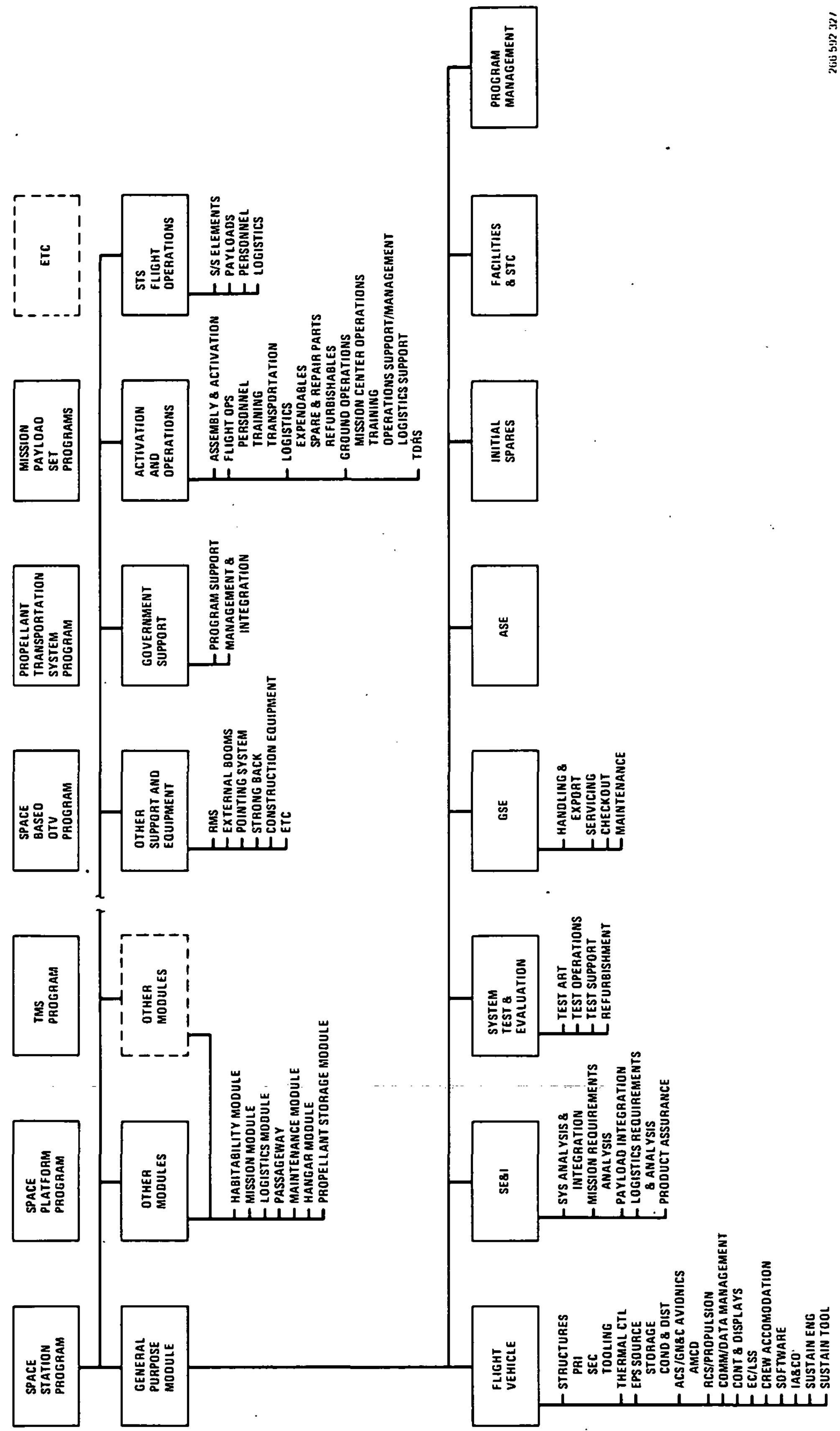

Figure 3-3. Space Station Program WBS

The nonrecurring or development portion of Phase C/D includes the one-time tasks and hardware to design and test the Space Station system. It includes the required design and analysis for all ground and flight hardware, including structural analysis, stress, dynamics, thermal, mass properties, etc. This nonrecurring category includes component development and test through component qualification, as well as all component development test hardware. This phase also includes all software development. In addition, this phase includes: system engineering and integration; system level test hardware and system test; GSE design, development test, and manufacture; facilities; and overall program management and administration.

The production portion of Phase C/D (unit cost estimate) includes all tasks and hardware necessary to provide one complete set of flight hardware equipment. It includes all material and component procurement, parts fabrication, and hardware refurbishment, subassembly, and final assembly. In addition, this category includes the required quality control/inspection task, an acceptance test procedure for sell-off to the customer, and program management and administration activities accomplished during the manufacturing process.

The operations phase includes all flight vehicle preparation, launch, and on-orbit operations associated with the Space Station system. It includes all ground support operations, STS transportation, and flight operations for placement and servicing, and the mission operations (ground) activities themselves, including mission control, data handling, support, etc., together with program management and administration during the operations period. It is assumed that the Shuttle transportation costs include all Shuttle-related activities such as on-line payload installation, mission operations center activities, flight crew costs, and other common ground operations/mission operations and activities and optimal services.

3.2.2 SYSTEM DEFINITION

3.2.2.1 Mission Payloads. A full discussion on the identification and selection of the mission payloads identified and considered in this study is in Volume II, Book 1, Sections 3 and 4. The full baseline mission set selected for the cost analysis is presented in Table 3-2 together with an estimate of the development time, scheduled start date to meet the identified IOC date, and the payload mass. Those payloads that will be attached to the station proper are also identified. Cost estimates of this mission set, including both the full set and station attached only, were then made; the results are discussed in Section 3.3.3.

Table 3-2. Baseline Mission Set (Sheet 1 of 9)

Mission	Development Duration (Years)	Baseline Scheduled Start Date	Payload Mass (Kilograms)	Station Attached Payload
• SCIENCE AND APPLICATIONS MISSIONS				
ASTROPHYSICS				
Astronomy				
0000 Starlab	4	1992	3280	X
0001 Large Deployable Reflector	4	1998	55000	
0002 Far UV Spectroscopy Explorer	3	1989	1360	
0003 Very Long Baseline Interferometry	3	1995	342	
0004 Space Telescope	4	1992	11600	
0005 Shuttle IR Telescope Facility	4	1990	7018	X
High Energy				
0030 Gamma Ray Observatory	3	1988	11000	
0031 High Throughput Mission	4	1999	10000	X
0032 Large Area Modular Array	4	1994	9516	X
0033 Advanced X-ray Astrophysics Facility	5	1991	10267	
0034 High Resolution X and Gamma Ray Spectrometer	4	1993	1768	X
0035 High Energy Isotope Experiment	3	1997	2800	
0036 Spectra of Cosmic Ray Nuclei	3	1996	3082	X
0037 Transition Radiation and Ionization Colorimeter	2	1996	5750	X
0038 X-ray Timing Explorer	3	1990	1000	
Solar Physics				
0060 Solar Internal Dynamics Mission	3	1991	4540	
0061 Solar Corona Diagnostics Mission	3	1993	1800	
0062 Advanced Solar Observatory	5	1995	11130	

Table 3-2. Baseline Mission Set (Sheet 2 of 9)

Mission	Development Duration (Years)	Baseline Scheduled Start Date	Payload Mass (Kilograms)	Station Attached Payload
• SCIENCE AND APPLICATIONS MISSIONS (Contd)				
EARTH AND PLANETARY EXPLORATION				
Planetary Observations				
0103 Mars Geochemistry/ Climatology Orbiter	4	1992	5600	
0104 Mars Aeronomy Orbiter	4	1992	5600	
0105 Venus Atmosphere Probe	4	1993	6000	
0106 Lunar Geochemistry Orbiter	4	1993	480	
0107 Titan Probe	4	1995	960	
0108 Saturn Orbiter	5	1997	1800	
0109 Mars Lander	5	1997	1700	
0110 Saturn Probe	5	1997	2170	
Solar System Missions				
0121 Comet T2 Rendezvous	4	1992	2200	
0122 Main-Belt Asteroid Rendez- vous	4	1992	2700	
0123 Comet HMP Sample Return	5	1994	1200	
0124 Near-Earth Asteroid Rendez- vous	4	1997	1170	
Earth Dynamics				
No payload elements identified in this Discipline				
Crustal Motion				
0151 Detection and Monitoring of Episodal Events	4	1998	3500	
0152 Geoscience-Crustal Dynamics Studies	3	1992	185	
Geopotential Fields				
0161 Earth Science Research- Geophysical Investigation	3	1998	400	

Table 3-2. Baseline Mission Set (Sheet 3 of 9)

Mission	Development Duration (Years)	Baseline Scheduled Start Date	Payload Mass (Kilograms)	Station Attached Payload
• SCIENCE AND APPLICATIONS MISSIONS (Contd)				
Earth Resources				
0171 Renewable Resources - Earth Science Research	4	1996	540	
0172 Operational Land Systems	4	1990	540	
0173 Shuttle Active Microwave Experiment (SAMEX-C)	4	1992	2000	X
0174 Earth Obs Instrument Devel (Microwave Tech)	3	1991	200	X
0175 Earth Obs Instrument Devel (Extra Visible & RF)	3	1994	1000	X
0176 EO Sensor/Technique/Analysis/Automated System Development	4	1992	2000	X
0177 Geoscience-Geology Remote Sensing	4	1990	540	
0179 Imaging Radar for Earth Resources Inventory & Monitoring	4	1996	2000	X
0180 Freeflying Imaging Radar Experiment (FIREX)	3	1992	600	
0181 Z - Continuous Coverage	4	1996	8578	
0182 Z-Hydrologic Cycle Priority	4	1998	8708	
0183 Z-Special Coverage	4	2000	18821	
0184 Z-Continuous and Special Coverage	4	2002	14260	
ENVIRONMENTAL OBSERVATIONS				
Weather/Climate				
0201 Satellite Doppler Meteorological Radar Tech Development	4	1999	2600	X
0202 Meteorology Instrument Group Development Payload	3	1993	1170	X
0203 Lightning Mapper	3	1998	900	
0204 Geosynchronous Microwave Sounder	4	1999	5850	

Table 3-2. Baseline Mission Set (Sheet 4 of 9)

Mission	Development Duration (Years)	Baseline Scheduled Start Date	Payload Mass (Kilograms)	Station Attached Payload
• SCIENCE AND APPLICATIONS MISSIONS (Contd)				
0205 Meteorology Instrument	3	1995	430	
0206 Geostationary Opnl. Env. Satellite (GOES) Follow-on	4	1994	500	
0207 TIROS Follow-on	3	1992	2000	
Ocean				
0221 Ocean Instrument Payload (OIP)	3	1994	480	
0221 Ocean Instrument Payload (OIP)	2	1998	480	
0222 Ocean Topography Experiment (TOPEX)	3	1988	1600	
Solar Terrestrial				
0241 Earth Radiation Budget Experiment (ERBE)	3	1991	55	
0242 Incoherent Scatter Radar	3	1996	1000	X
0242 Incoherent Scatter Radar	2	1998	1000	
0243 Topside Digital Ionosonde/HF Radar	3	1997	500	
0243 Topside Digital Inosonde/HF Radar	2	1999	500	
0244 Solar Terrestrial Observatory-Manned	5	2000	16500	
0245 Space Plasma Physics Payload - Manned	3	1998	3183	
0246 Solar Terrestrial Observatory-Unmanned	5	1994	7314	
0247 Space Plasma Physics Payload-Unmanned	3	1992	3183	
Atmospheric Research				
0261 High Resolution Doppler Imager (HRDI)	2	1990	76	
0262 Measurement of Air Pollution from Satellites (MAPS)	2	1990	100	

Table 3-2. Baseline Mission Set (Sheet 5 of 9)

Mission	Development Duration (Years)	Baseline Scheduled Start Date	Payload Mass (Kilograms)	Station Attached Payload
• SCIENCE AND APPLICATIONS MISSIONS (Contd)				
0263 CO_2 LIDAR for Atmospheric Measurements	3	1998	4000	
0264 LIDAR Facility	2	1992	1900	
0265 Upper Atmosphere Research Payload-Development	4	1994	2500	X
0266 WINDSAT	3	1995	2260	
0267 Upper Atmosphere Research Payload-Operational	3	1994	1108	
LIFE SCIENCES				
Biological Science				
0300 Human Research Lab.	5	1990	7300	X
0301 Animal and Plant Research Lab.	5	1990	8500	
Operational Medicine				
0322 EVA Performance and Productivity	3	1990	270	X
Life Support				
0340 $H_2/O_2/N_2$ Regenerative Systems	4	1991	1280	X
0341 CELSS Experimental Systems	4	1992	2625	X
0342 Dedicated CELSS Module	5	1996	10500	X
0343 CELSS Pallet	4	1996	1300	X
Materials Processing				
0400 Research and Development Facility	4	1990	1736	X
0401 R&D/Proof of Concept Facility	4	1994	3224	X

Table 3-2. Baseline Mission Set (Sheet 6 of 9)

Mission	Development Duration (Years)	Baseline Scheduled Start Date	Payload Mass (Kilograms)	Station Attached Payload
• COMMERCIAL MISSIONS				
EARTH AND OCEAN OBSERVATIONS				
1000 Geological Reconnaissance		1990	650	
1001 Remote Atmospheric Sensing		1990	650	
1002 Worldwide Cotton Acreage and Production		1990	N/A	
1003 Petro/Mineral Experiment				
COMMUNICATIONS				
1100 Small Communication Satellite		1990	816	
1101 Medium Communication Satellite		1990	2041	
1102 Large Communication Satellite		1994	2313	
1103 Experimental Geo Platform		1990	5450	
1104 Operational Geo Platform		1994	5450	
1106 Large Deployable Antenna		1992	500	X
1107 RFI Measurements		1994	50	X
1108 Laser Communications		1991	140	X
1109 Open Envelope Tube		1993	157	X
1110 Spaceborne Interferometer		1995	60	X
1111 Millimeter Wave Propagation		1991	40	X
MATERIALS PROCESSING				
1200 Pilot - Biological Processing Facility	3	1992	1050	X
1201 Pilot - Containerless Processing Facility	3	1994	3900	X
1202 Pilot - Furnace Processing Facility	3	1994	4452	X
1203 Commercial - Biological Processing Facility		1995	2100	X
1204 Commercial - Containerless Processing Facility		1997	5700	X

Table 3-2. Baseline Mission Set (Sheet 7 of 9)

Mission	Development Duration (Years)	Baseline Scheduled Start Date	Payload Mass (Kilograms)	Station Attached Payload
• COMMERCIAL MISSIONS (Contd)				
1205 Commercial - Furnace Processing Facility		1997	6325	X
1206 Electrophoresis Free-Flying		1996	9987	
1207 Electrophoretic Separation		1990	300	X
1208 Crystal Growth		1992	N/A	X
1209 Metal Clusters and Crystal Growth		1990	100	X
1210 Enzyme Production and Separation		1990	N/A	X
1211 Silicon Crystals		1990	300	X
1212 Heat Resistant Alloys		1997	5000	
1213 Chemical Reactions		1990	N/A	X
1214 Space Isothermal Furnace System (SIFS)		1990	N/A	X
INDUSTRIAL SERVICES				
1300 Radiation Hardened Computer		1990	50	X
1301 Full-Body Teleoperator		1995	300	X
1302 Gamma Ray Astronomy		1990	2000	
1303 Plants in Controlled Env Life Support Systems (CELSS)		1990	N/A	X
1304 Controlled Environment Life Support Systems (CELSS)		1996	1500	X
1305 Communication Satellite Service/Handling		1992	N/A	X
• *TECHNOLOGY DEVELOPMENT*				
MATERIALS & STRUCTURES				
2001 Strain and Acoustic Sensors	2	1990	50	X
2002 Spacecraft Materials Technology	2	1991	150	X
2003 Materials and Coatings	2	1991	250	X
2004 Thermal Shape Control	2	1993	1000	X

Table 3-2. Baseline Mission Set (Sheet 8 of 9)

Mission	Development Duration (Years)	Baseline Scheduled Start Date	Payload Mass (Kilograms)	Station Attached Payload
• TECHNOLOGY DEVELOPMENT (Contd)				
2005 Dynamics of Flimsy Structures	2	1994	1000	X
2006 Active Optics Technology	4	1994	10000	X
2007 Large Structures Technology	5	2002	100000	X
ENERGY CONVERSION				
2101 Low-Cost Modular Solar Systems	2	1991	30	X
2103 Ion Effects on LEO Power Systems	2	1992	500	X
2104 Large Solar Concentrator	3	1995	5000	X
2105 Solar Pumped Lasers	3	1996	200	X
2106 Laser/Electric Energy Conversion	2	1996	500	X
2107 Solar Sustained Plasmas	2	1997	2000	X
2108 Space Nuclear Reactor	8	1997	2500	X
COMPUTER SCIENCE & ELECTRONICS				
2201 Attitude Control - System Identification Experiment	3	1994	100	X
2202 Attitude Control - Adaptive Control Experiment	2	1994	100	X
2203 Attitude Control - Distributed Control Experiment	2	1995	100	X
2204 Advanced Adaptive Control Technology Demonstration	4	1990	500	X
PROPULSION				
2301 Controller Acceleration Propulsion Test	2	1994	45	X
2302 Laser Propulsion Test	3	1996	100	X

Table 3-2. Baseline Mission Set (Sheet 9 of 9)

Mission	Development Duration (Years)	Baseline Scheduled Start Date	Payload Mass (Kilograms)	Station Attached Payload
• TECHNOLOGY DEVELOPMENT (Contd)				
CONTROL & HUMAN FACTORS				
2401 Manipulator Controls Technology	3	1991	600	X
2402 Advanced EVA Technology	4	1990	500	X
SPACE STATION SYSTEMS & OPERATIONS				
2501 Liquid Droplet Radiator	2	1996	1000	X
2502 Advanced Control Device	3	1994	400	X
2503 Space Component Lifetime Technology	2	1990	300	X
2504 OTV Payload Handling	3	1992	2000	X
2505 Payload Servicing and Repair	3	1992	500	X
2506 OTV Propellant Transfer & Storage	3	1991	2000	X
2507 OTV Propellant Liquification	3	1991	1000	X
2508 OTV Docking & Berthing	3	1991	5900	X
2509 OTV Maintenance	3	1992	3000	X
2510 Tethered Dynamics Technology	3	1995	3000	
FLUID & THERMAL PHYSICS, PHYSICS AND CHEMISTRY				
2601 Space Mfg. Lightweight Heat Pumps	2	1992	1000	X
• OPERATIONS				
4000 Manned GEO Sortie	6	1999	4535	
4001 Manned GEO Support Module	6	2002	8160	

3.2.2.2 Space Station. The Space Station architecture and evolutionary options have been generally defined and are discussed in some detail in Volume II, Book 2. The elements of our "all up" space station concept are shown in Figure 3-4. The evolution for the baseline station is also shown in Figure 3-5.

The following four basic options have been examined:

a. A single research station

b. A single space based OTV operations station

c. Two stations - one research and one a space based OTV operations station

d. A single station combining research and a space based OTV operations station

The element quantities associated with each of these options are shown in Table 3-3.

The parametric model used to generate program cost estimates requires definition input at the subsystem level. It was necessary, therefore, to develop description, weight, and performance information for each station element at this level. These data are presented in Table 3-4 for the research station and Table 3-5 for the operations capability portion. These input data are necessarily very ROM because of their generic nature. Because of the utilization of much of the hardware across various modules, a commonality factor representing percentage of a new design is also identified, subsystem by subsystem, for each module.

The time phasing of the baseline concept is presented in Figure 3-6.

3.2.2.3 Other Program Elements.

The principal additional elements of the baseline station concept are the SBOTV and a shuttle derived ET tanker concept. These are illustrated in Figures 3-7 and 3-8 respectively.

The baseline STS traffic model developed for the selected scenario is shown in Table 3-6. This traffic model was used to develop STS operations funding shown in Section 4.

3.3 PROGRAM OPTION COST ESTIMATES

3.3.1 SPACE STATION ELEMENT COSTS. Using the parametric cost model and the generic subsystem input data, ROM costs have been developed for each of the architecture elements. The cost estimate of a typical element, the General Purpose module, is shown in Table 3-7. It gives the input, the nonrecurring (development) cost, and the unit production cost associated with each of the subsystems and the wraparound cost elements. These subsystem level estimates were made for each of the major station modules or elements.

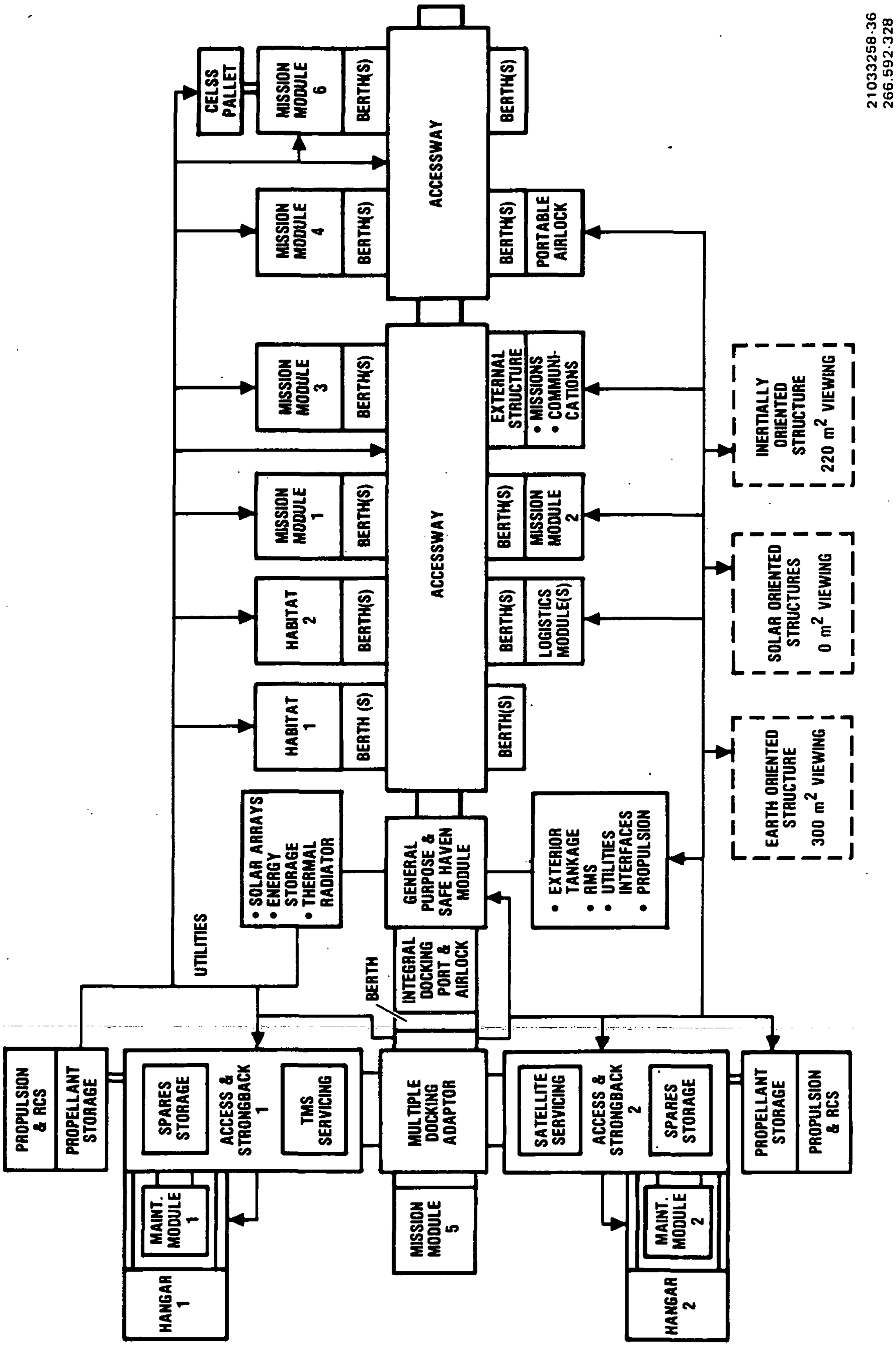

Figure 3-4. Manned Space Station Architecture - 1996-2000

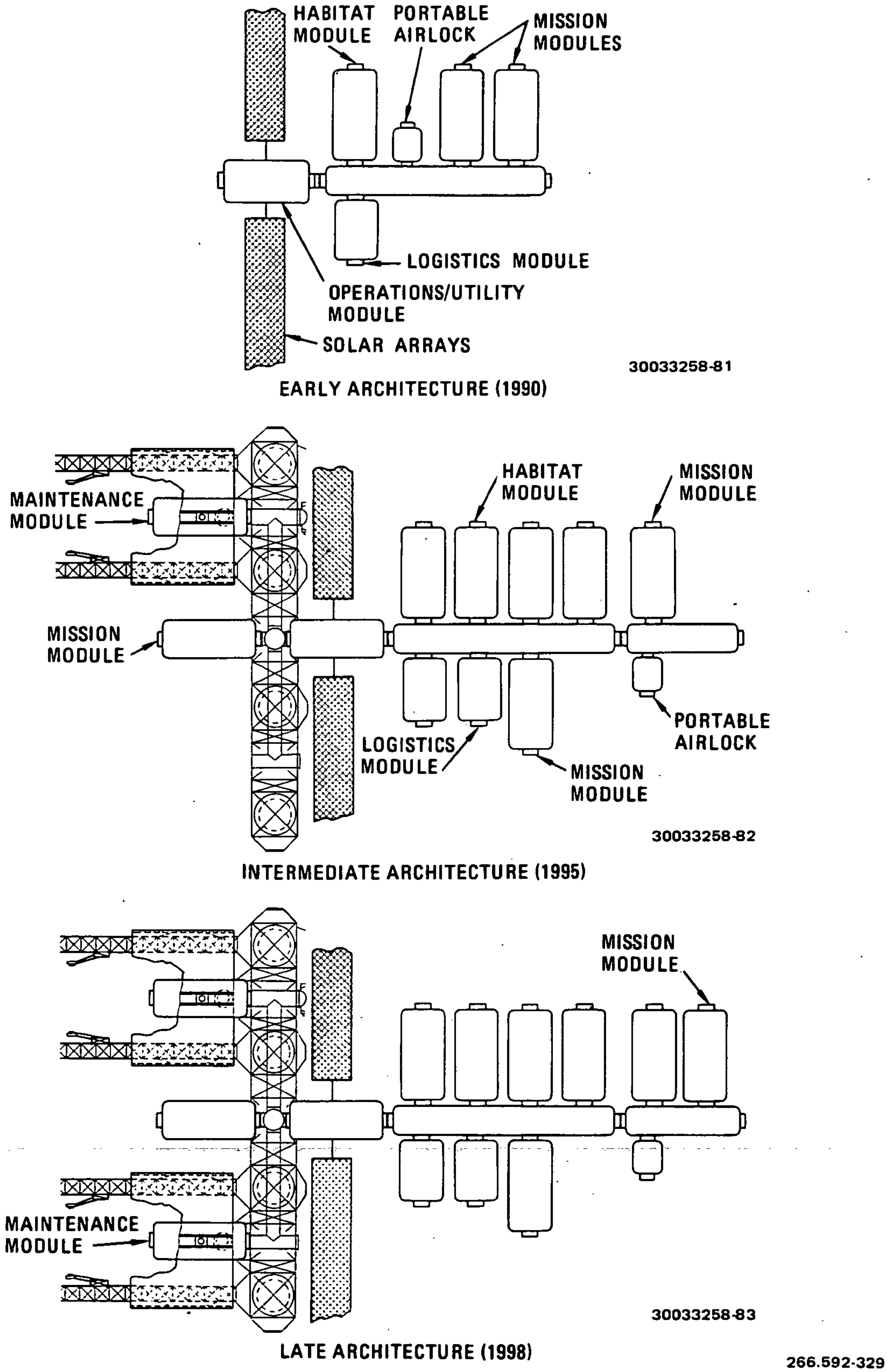

Figure 3-5. Evolution of Baseline Space Station Architecture

Table 3-3. Space Station Module Quantity

Module/Item	Research Station	Research Station + SBOTV Operations Station	SBOTV Operations Station	Baseline Combined Research + SBOTV Operations Station
General purpose	1	1		1
Habitability	2	2		2
Mission	5	5		6
Logistics	3	3		6
Passageway	2	2		2
External booms	4	4		4
RMS	1	1		1
General purpose		1	1	
Habitability		1	1	
Mission		1	1	
Logistics		3	3	
Maintenance		2	2	2
Hangar		2	2	2
Propellant storage		4	4	4
Passageway		2	2	2
External booms I		2	2	2
External booms II		2	2	2
RMS		2	2	2

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3.3.2. SPACE STATION PROGRAM COSTS. The nonrecurring (development) and unit production costs for each of the principal scenarios estimated are shown in Tables 3-8 through 3-11. They are:

a. A research station only with an IOC in 1990 growing to full capability by 1996.

b. An operations only station that will accommodate TMS and space based OTV operations starting in 1994.

c. Two independent stations, one research and one operations.

d. A combined research and operations station.

The latter option is referred to in this volume as the baseline concept. The required availability of the elements of each of these options are shown in Tables 3-12 through 3-15. The resulting costs are then shown in Tables 3-8 through 3-11, which also show module quantities and include all commonality effects according to the development sequence. The associated government costs are also included.

Table 3-4. Space Station Element Definition - Research Portion

	UNITS	GENERAL PURPOSE		HABITABILITY		MISSION		LOGISTICS		PASSAGEWAY	
		INPUT	% COMMON	INPUT	% COMMON	INPUT	% COMMON	INPUT	% COMMON	INPUT	% COMMON
STRUCTURE (PRI)	KG	7,300	0	7,300	90	7,300	90	6,800	25	4,500	25
STRUCTURE (SEC)	KG	400	0	400	50	400	50	400	25	750	50
THERMAL CTL	KG	13,000	0	3,000	20	3,000	80	1,000	75	1,000	70
ACS/GNEC AVIONICS	KG	400	0	0	0	0	0	0	0	0	0
AMCS	NO. & FT-LB MOMENTUM	5 X 5,000	0	0	0	0	0	0	0	0	0
RCS	KG	5,000	0	0	0	0	0	0	0	0	0
EPS SOLAR ARRAY	KW	20	0	0	0	0	0	0	0	0	0
EPS BATTERIES	NO. & KW-HR	10 X 2.63	0	0	0	0	0	0	0	0	0
EPS C&D	KG	700	0	700	80	700	80	50	0	50	50
COMM/DM	KG	275	0	500	40	500	80	100	70	100	70
EC/LSS	KG	2,200	0	1,400	80	1,400	80	900	50	900	50
CREW/ACCOM	KG	200	0	800	80	200	90	200	90	200	90
SOFTWARE	LINES OF CODE	200,000	0	0	0	0	0	0	0	0	0
CONTROLS & DISPLAYS	KG	4,700	0	0	0	0	0	0	0	0	0

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Table 3-5. Space Station Element Definition - Operations Portions

	UNITS	MAINTENANCE		EXTERNAL STRUCTURE		PROPELLANT		HANGAR		PASSAGEWAY	
		WT	% COMMON	WT	% COMMON	WT	% COMMON	WT	% COMMON	WT	% COMMON
STRUCTURE (PRI)	KG	6,080	80	4,500	0	7,400	0	2,400	0	3,700	75
STRUCTURE (SEC)	KG	500	50	500	20	3,300	10	400	50	550	50
THERMAL CTL	KG	2,400	30	0	0	2,300	0	0	0	600	20
ACS/GN&C AVIONICS	KG	0	0	0	0	0	0	0	0	0	0
AMCD	NO. & FT-LB MOMENTUM	0	0	0	0	0	0	0	0	0	0
RCS	KG	0	0	0	0	0	0	0	0	0	0
EPS SOLAR ARRAY	KW	0	0	0	0	0	0	0	0	0	0
EPS BATTERIES	NO. & KW-HR	0	0	0	0	0	0	0	0	0	0
EPS C&D	KG	700	20	300	0	300	50	700	80	700	80
COMM/DM	KG	500	50	20	50	0	0	100	50	100	50
EC/LSS	KG	1,100	80	0	0	0	0	0	0	700	90
CREW/ACCOM	KG	200	90	20	50	0	0	200	80	200	80
SOFTWARE	LINES OF CODES	0	0	0	0	0	0	0	0	0	0
CONTROLS & DISPLAYS	KG	0	0	0	0	0	0	0	0	0	0

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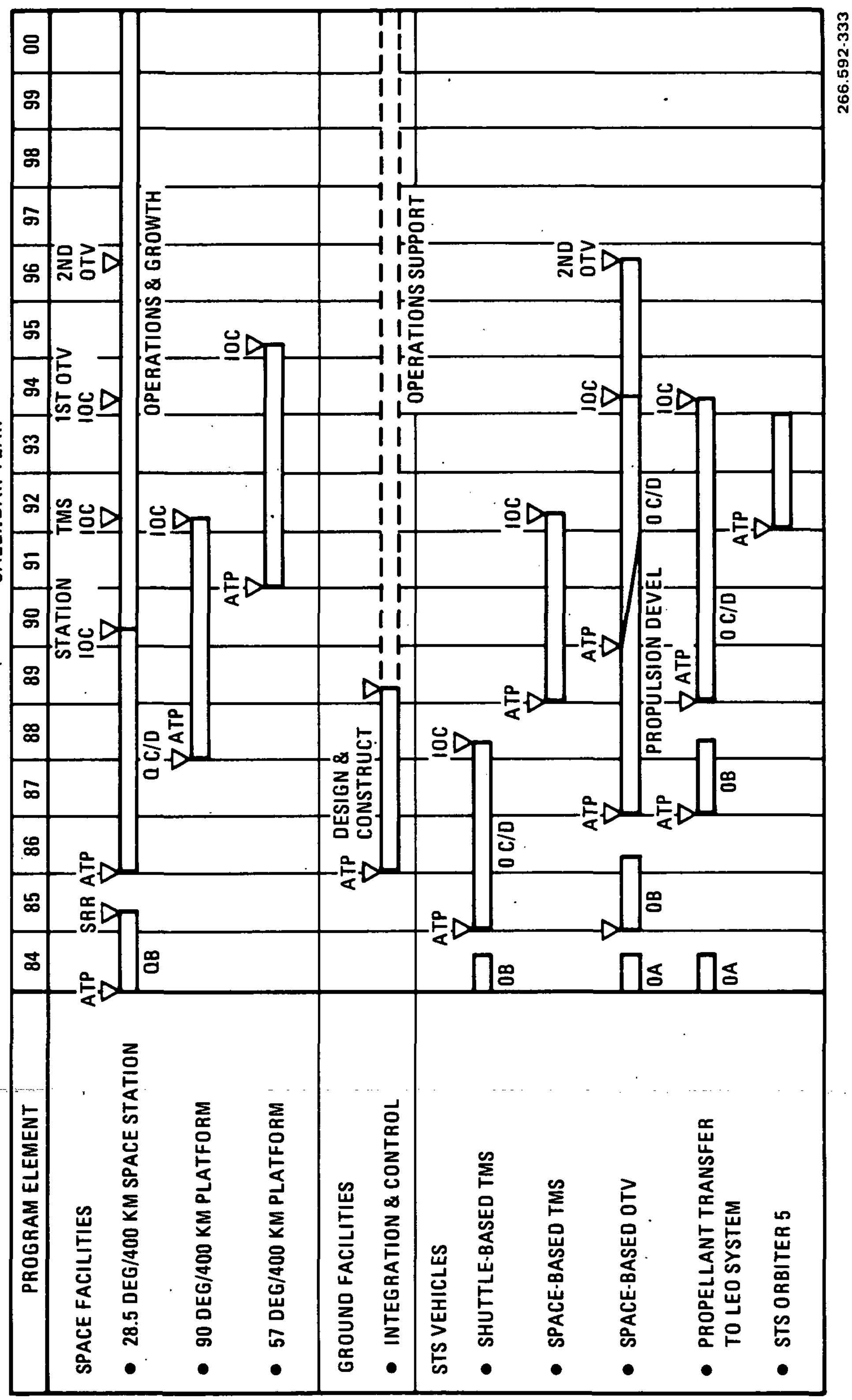


Figure 3-6. Baseline Space Station Program

Advantages
- Free from Shuttle constraints (size, loads)
- Reusable (lower cost)
- Modularity (mix & match capability)

Key issues
- Long-term space exposure
- Orbital integration, servicing
- Efficiency (low weight, high Isp)
- Low-cost operations (propellant delivery to LEO)
- Deployment & retrieval
- Future payloads & mission characteristics

Technology needs
- Lightweight (thin gage) tanks
- Lightweight (composite) structure
- Lightweight/high temperature aerobrake materials
- Long life/space maintainability engine (low weight, high Isp
- Cryogenic propellant management — thermal control (MLI insulation, mixing, venting), propellant acquisition gaging
- Meteoroid & space debris protection
- Redundant, fault-tolerant, hardened avionics
- Auto rendezvous/docking

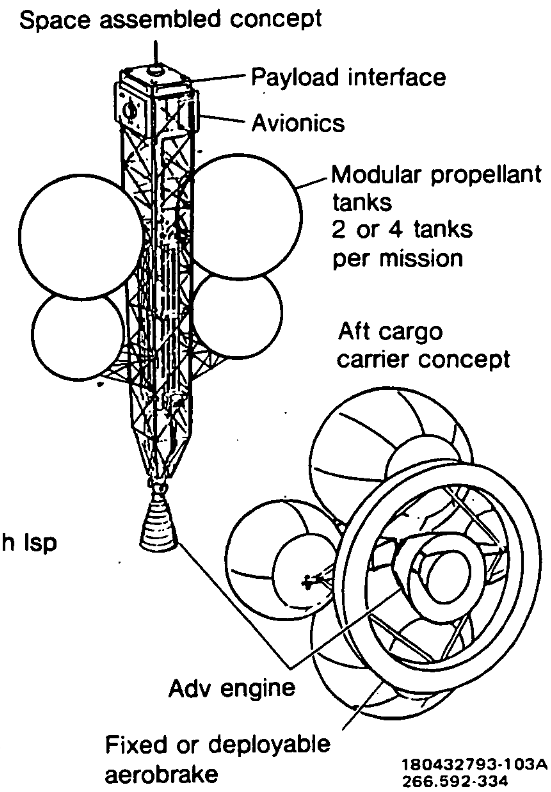
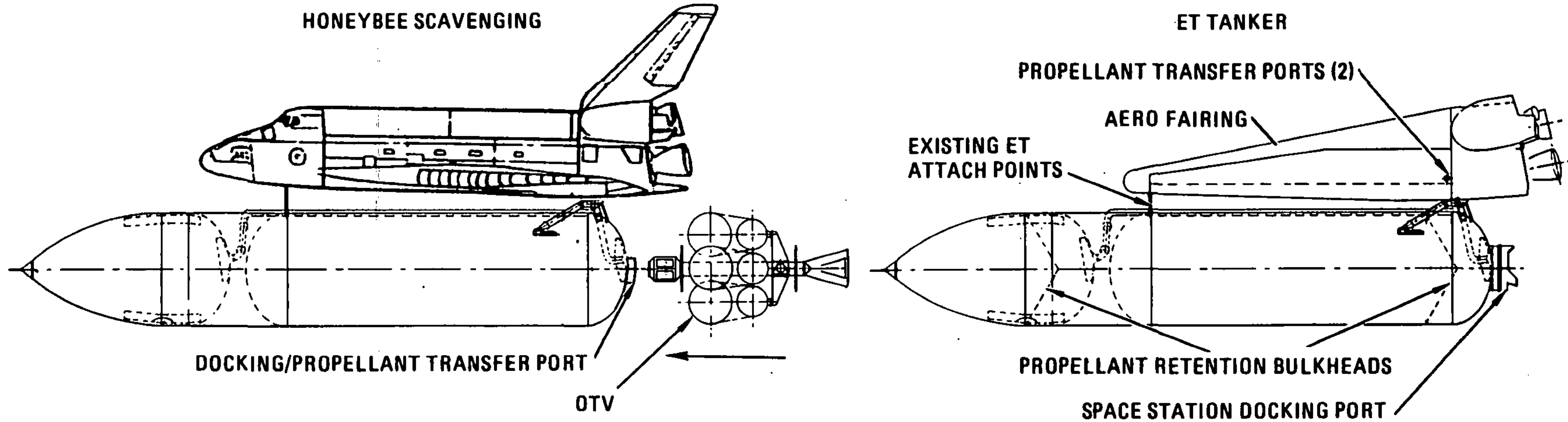


Figure 3-7. Space-Based OTV Concepts

The total nonrecurring and production costs for these four options are summarized in Table 3-16. The expenditure of funds for the research station (Case A) at IOC in 1990 is $5.5 billion with full capability expenditure of $6.3 billion. The operations station cost is $7.7 billion (Case B); however, much of the capability for the research station is included. Therefore, a combined station, the baseline (Case D), will cost only $1.8 billion additional. From the alternate viewpoint, with an early research capability and a later operations capability, the operation cost increment is about $3.2 billion. The cost of two independent stations is about $9.9 billion.

3.3.3 MISSION PAYLOAD SET FUNDING REQUIREMENTS. A major portion of this study effort has been devoted to the collection, identification, and validation of current and future mission requirements covering the entire spectrum of disciplines and desired accommodations. This effort has been documented in Volume II, Book 1 (and its Appendix) of this report. It is readily apparent that cost and funding are key parameters in the evaluation of raw requirement sets and in the establishment of a realistic integrated mission set to serve as a basis for Space Station implementation architecture.



PERFORMANCE

	Honeybee Scavenging	ET Tanker
• PROPELLANT DELIVERED TO STATION PER MISSION –	11,300 POUNDS	200,000 POUNDS
• PROPELLANT DELIVERED TO STATION PER YEAR –	230,000-270,000 POUNDS	600,000 POUNDS+
• PROPELLANT DELIVERY COST –	$250/POUND	$350/POUND

KEY SYSTEM ISSUES

- ADD ET SYSTEMS WEIGHT
- ET/OTV STABILITY & CONTROL
- SAFETY/RELIABILITY
- ENGINE MODULE DESIGN FOR ON-ORBIT DISASSEMBLY
- ADAPTABILITY TO PAYLOAD CARRIAGE
- DEVELOPMENT COST

ET TANKER SATISFIES ENTIRE OTV MISSION MODEL PROPELLANT REQUIREMENTS WITH MINIMUM DISRUPTION OF STS PAYLOAD DELIVERY SCHEDULE

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Figure 3-8. Propellant Delivery System Concepts

Table 3-6. STS Traffic Model - Combined Space Station Program

Year	90	91	92	93	94	95	96	97	98	99	00
NASA	10	7	12	14	14	14	13	5	16	6	6
Commercial	11	11	15	12	12	10	8	12	0	7	10
DoD	14	14	12	16	17	13	13	15	20	12	16
Total	35	32	39	42	43	37	34	32	36	25	32

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Table 3-7. Space Station Preliminary Cost Estimate (1984 M$)

MODULE — GENERAL PURPOSE

Cost Element	Size Parameter	Development Cost	Unit Cost
Flight vehicle			
Structure (PRI)	16093.6	159.68	28.32
Structures (SEC)	881.8	13.08	2.08
Tooling		40.48	
Thermal control	28659.8	56.76	38.61
ACS/GN&C avionics	881.8	46.21	13.60
ACS AMCD	5000.0	13.26	2.67
RCS	11023.0	42.17	19.57
EPS solar array	20.0	43.06	26.11
EPS batteries	2.6	4.17	3.04
EPS cond & dist	1543.2	33.44	11.20
Comm/data mgmt	606.3	71.63	12.39
Cont & displays	10361.6	45.78	20.37
EC/LSS	4850.1	212.11	23.31
Crew accommodations	440.9	54.98	1.48
Flight software	200000.0	103.60	
Subtotal		940.41	202.75
IA&CO			24.33
Sustain eng			17.03
SE&I		141.06	
System test		457.66	
Test article		366.71	
Test operations		90.94	
GSE		188.08	
Initial spares		60.83	
Program management		125.16	17.09
Total		1913.21	261.21

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Table 3-8. Research Station

	Dev	Cost (1984 $M) Unit	Qty	Production
GP Module	1913	261	1	261
Habitat Module	619	125	2	250
Mission Module	350	123	5	615
Logistic Module	330	63	3	189
Passageway	280	55	2	110
External Booms	100	10	4	40
RMS	20	10	1	10
Power	-	26	8	208
Total	3612			1683
Gov't	903			118
	4515			1801
Grand Total		6316		

Table 3-9. SBOTV Operations Station

	Dev	Cost (1984 $M) Unit	Qty	Production
GP Module	1913	261	1	261
Habitat Module	619	125	1	125
Mission Module	350	123	1	123
Logistic Module	330	63	3	189
Maintenance Module	345	114	2	228
Hangar Module	248	39	2	78
Propellant Module	595	70	4	280
Passageway	148	60	2	120
External Structure I	151	40	2	80
External Structure II	75	20	2	40
RMS	20	10	2	20
Power	-	26	1	26
Total	4794			1570
	1199			110
	5993			1680
Grand Total		7673		

Table 3-10. Research Station and SBOTV Operations Station

	Dev	Unit	Qty	Production
Research Station	4515			1801
SBOTV Operating Station				
GP Module	-	261	1	261
Habitability Module	-	125	1	125
Mission Module	-	123	1	123
Logistic Module	-	63	3	189
Maintenance Module	345	114	2	228
Hangar Module	248	39	2	78
Propellant Module	595	70	4	280
Passageway	148	60	2	120
External Structure I	151	40	2	80
External Structure II	75	20	2	40
RMS	-	10	2	20
Power	-	26	1	26
Total	1562			1570
Gov't	391			110
	1953			1680
Research Station	6468			3481
Grand Total		9949		

In order to provide first-cut "ballpark" cost and funding information for these evaluations, a simplified cost-estimating methodology was developed. A parametric approach that uses a single cost estimating relationship (CER) to determine program acquisition costs (development and production of one unit) was chosen. The proper coefficients for the CER were calibrated using cost estimates of existing and planned mission payloads. The CER is adjusted for each payload cost estimate by using complexity and commonality factors. The mission payloads are grouped according to technology areas and complexities, with each group such as optical imaging, general scientific, planetary, etc. assigned a complexity factor. Each payload is assigned another factor based on its commonality with other payloads within the group. The addition of operating costs, calculated as a percentage of program acquisition costs, completes the cost development procedure.

Table 3-11. Research and SBOTV Operations (Combined) Station

	Dev	Unit	Qty	Production
GP Module	1913	261	1	261
Habitat Module	619	125	2	250
Mission Module	350	123	6	738
Logistic Module	330	63	6	378
External Booms	100	10	4	40
Maintenance Module	345	114	2	228
Hangar Module	248	39	2	78
Propellant Module	595	70	4	280
Passageway I	280	54	2	108
Passageway II	148	60	2	120
External Structure I	151	40	2	80
External Structure II	75	20	2	40
RMS	20	10	3	30
Power	-	26	8	208
Total	5174			2839
	1294			199
	6468			3038
Grand Total		9506		

Table 3-12. Research Space Station Element Availability Requirements

Module	IOC	Growth
General Purpose	90	94
Habitat	90	91/93/94
Mission	90	
Logistic	90	
External Booms	90	
Maintenance		
Hangar		
Propellant		
Passageway I	90	94
Passageway II		
External Structure I		
External Structure II		
RMS	90	
Power	90	92/94/96

Table 3-13. SBOTV Operations Space Station Element Availability Requirements

Module	IOC	Growth
General Purpose	94	
Habitat	94	
Mission	94	
Logistic	94	
External Booms		
Maintenance	93	96
Hangar	93	96
Propellant	93	94/95/96
Passageway I		
Passageway II	94	
External Structure I	94	96
External Structure II	94	96
RMS	94	96
Power	94	

Table 3-14. Research Then SBOTV Operations Space Stations Element Availability Requirements

Module	IOC	Growth
General Purpose	90/94	
Habitat	90/94	94
Mission	90/94	91/93/94
Logistic	90/94	
External Booms	90	
Maintenance	93	96
Hangar	93	96
Propellant	93	94/95/96
Passageway I	90	94
Passageway II	94	
External Structure I	94	96
External Structure II	94	96
RMS	90/94	96
Power	90/94	92/94/96

Table 3-15. Baseline Combined Space Station Element Availability Requirements

Module	IOC	Growth
General Purpose	90	
Habitat	90	94
Mission	90	91/93/94/96
Logistic	90	94
External Booms	90	
Maintenance	93	96
Hangar	93	96
Propellant	93	94/95/96
Passageway I	90	94
Passageway II	94	
External Structure I	93	96
External Structure II	93	96
RMS	90	93/96
Power	90	92/94/96

Table 3-16. Preliminary Space Station Program Cost Summary

Case		Cost (FY84 M$)
	Research station (to IOC)	5,485
A	Research station	6,316
B	SBOTV operations station	7,673
C	Research station, then SBOTV operations station	9,949
D	Combined SBOTV operations & research station	9,506

Once these costs are developed, a computerized phased-funding model is used to individually spread the costs of each payload and then sum them by discipline. Figure 3-9 graphically displays the funding profile of the full baseline mission set together with the projected NASA budget for experiment payloads and spacecraft contained as line items in the FY 1983 NASA budget. This baseline set, previously listed in Table 3-2, includes free flyer, planetary,

station-attached, and platform payloads. All commercial mission payloads are assumed to fund themselves, with the exception of the pilot Materials Processing mission payloads, which are assumed to be partially funded by NASA. As can be seen, Astrophysics and Planetary Exploration account for the majority of the baseline mission set funding, especially in the early years of the program. Budgetary constraints may limit the number of missions flown. If the current funding level remains constant, only about one-third of those mission payloads included in the baseline mission set can fly as scheduled.

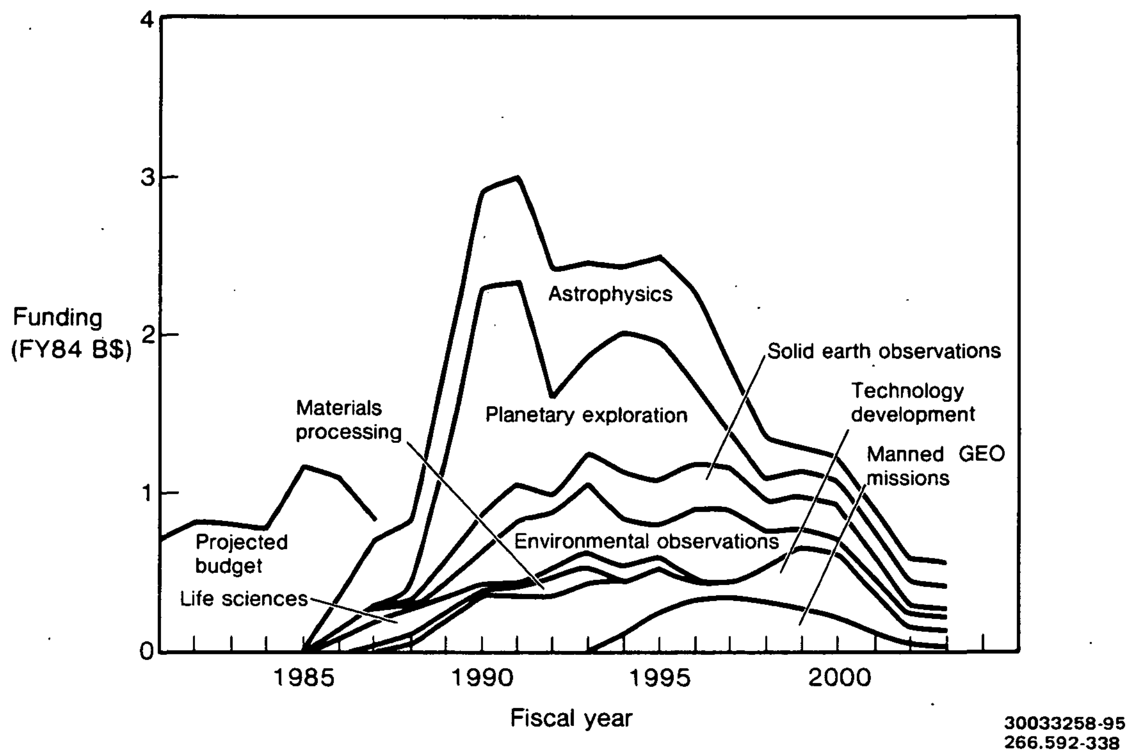

Figure 3-9. Funding Requirements - Full Mission Payload Set

Figure 3-10 shows the funding profile for those mission payloads to be flown in the Space Station attached mode. Accommodation of all the station-attached payloads identified in the baseline mission set would require approximately $1 billion per year in the peak-funding years of 1991 and 1992. This is about one-third of the peak-year funding amount needed to accommodate the total baseline mission set. Astrophysics is again a major cost contributor; however, Technology Development accounts for the largest percentage of the total station-attached mission set cost.

The funding profiles are shown for each of the disciplines of the full user information mission set (total missions identified) in Figures 3-11 through 3-20 and from the baseline (revised and integrated) mission set in Figures 3-21 through 3-28.

These profiles include the current NASA budget and 1981-1987 projection and a line of 5% growth from the average (1981-1987).

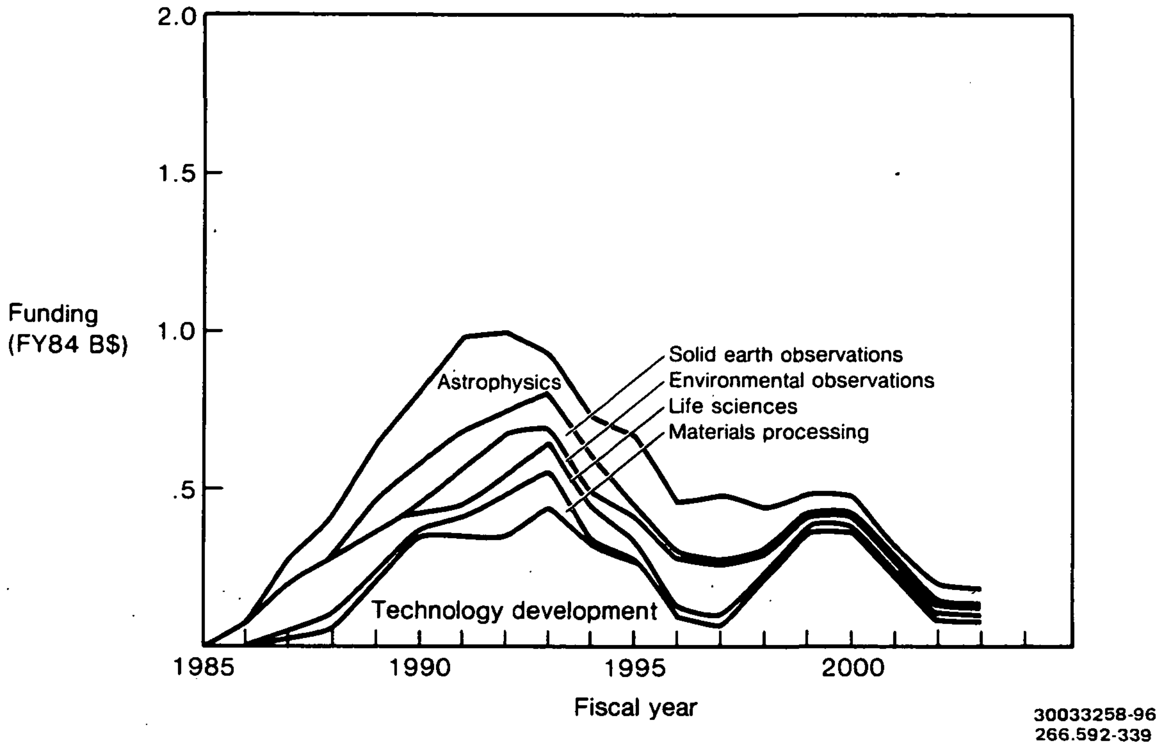

Figure 3-10. Funding Requirements - Mission Payload Set (Station-Attached)

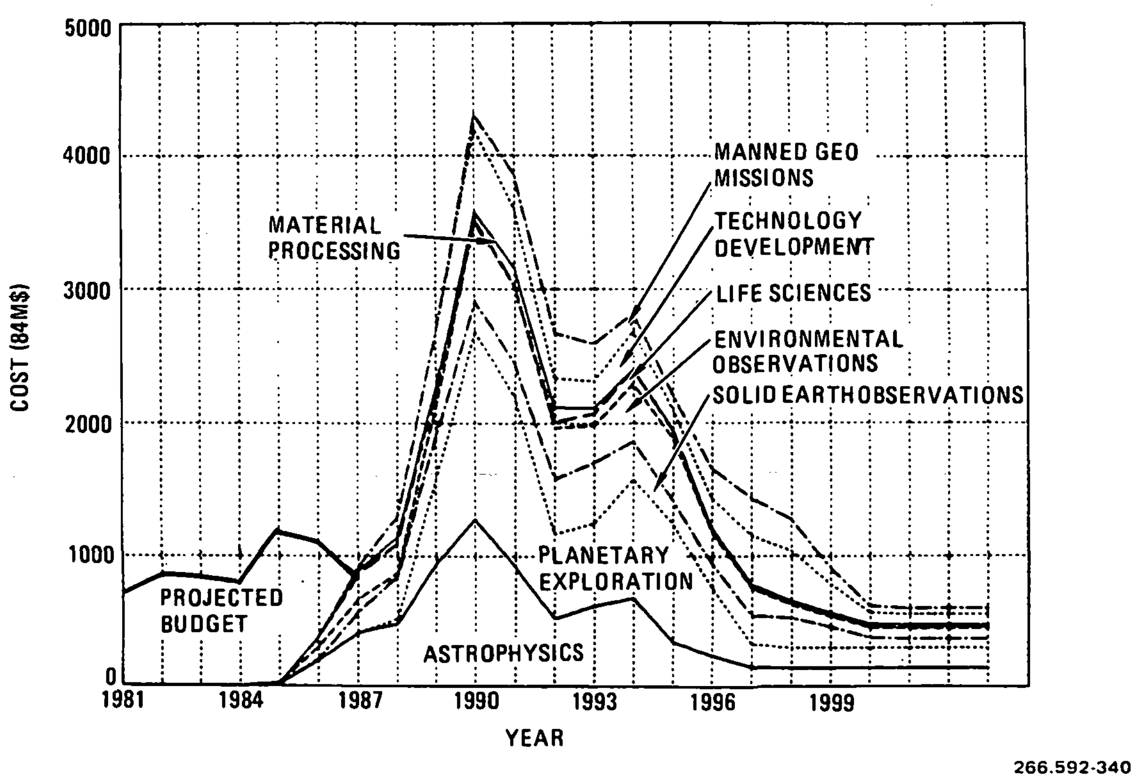

Figure 3-11. User Information Mission Set Funding - Total Program by Discipline

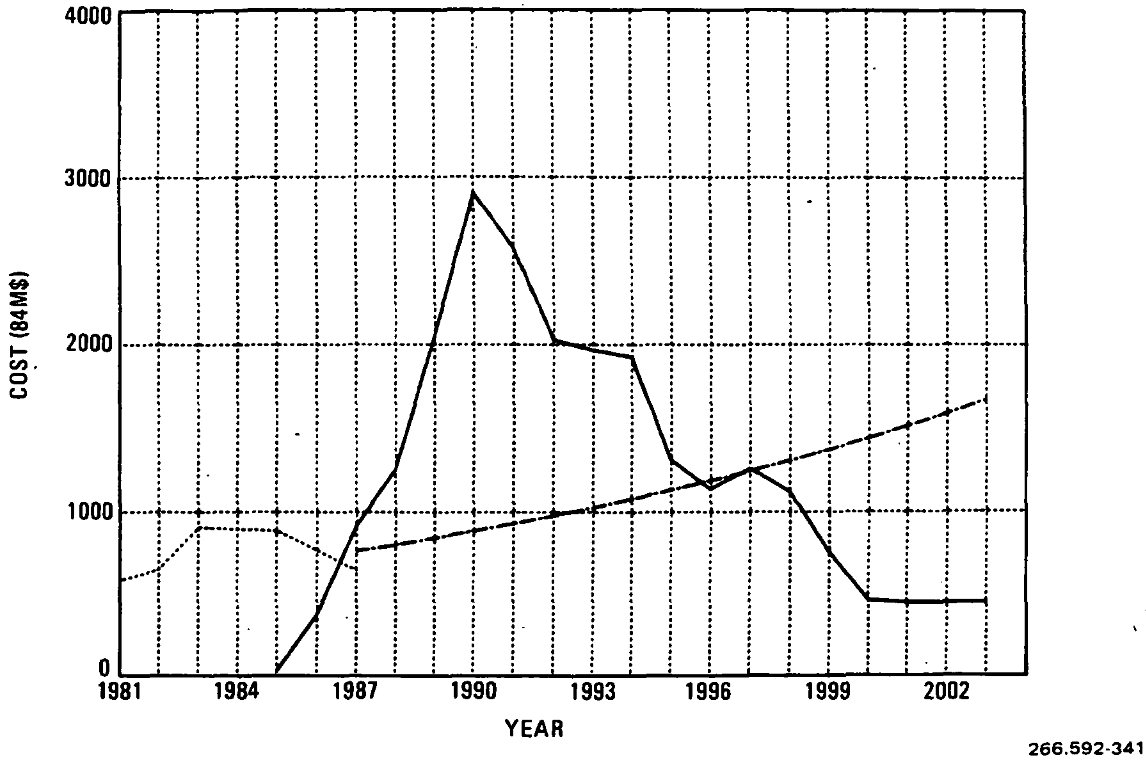

Figure 3-12. User Information Mission Set Funding - Total Program Excluding Planetary Exploration

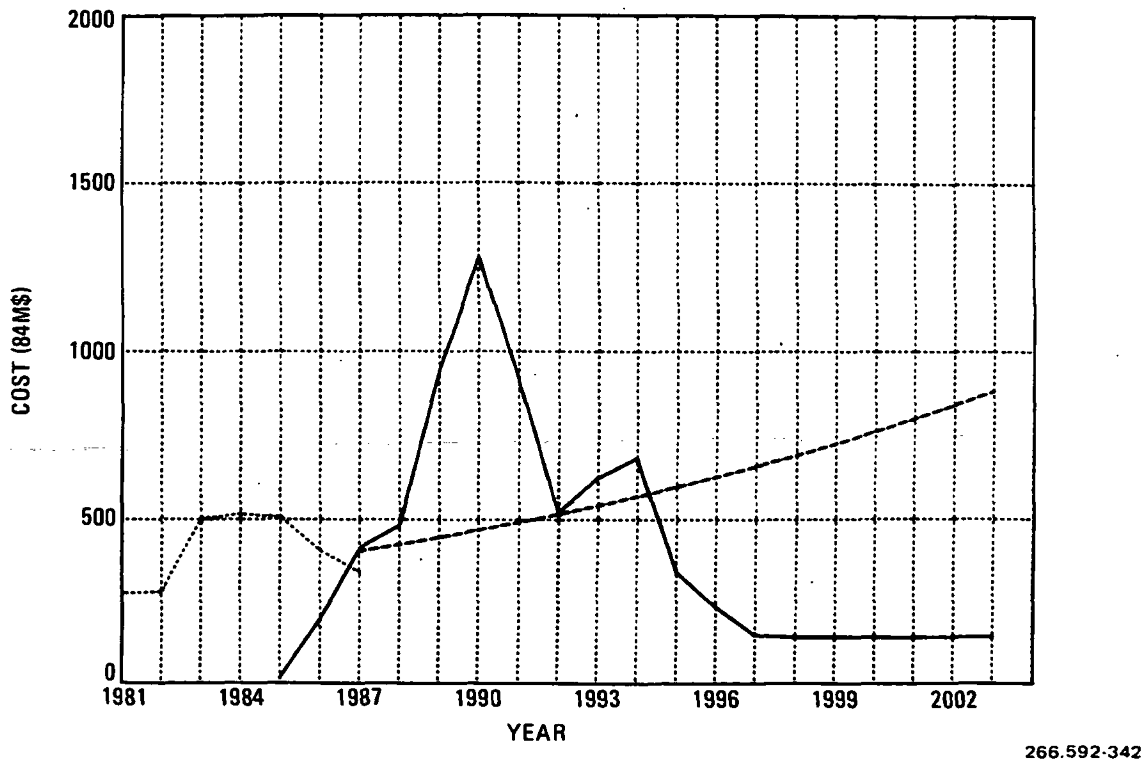

Figure 3-13. User Information Mission Set Funding - Astrophysics

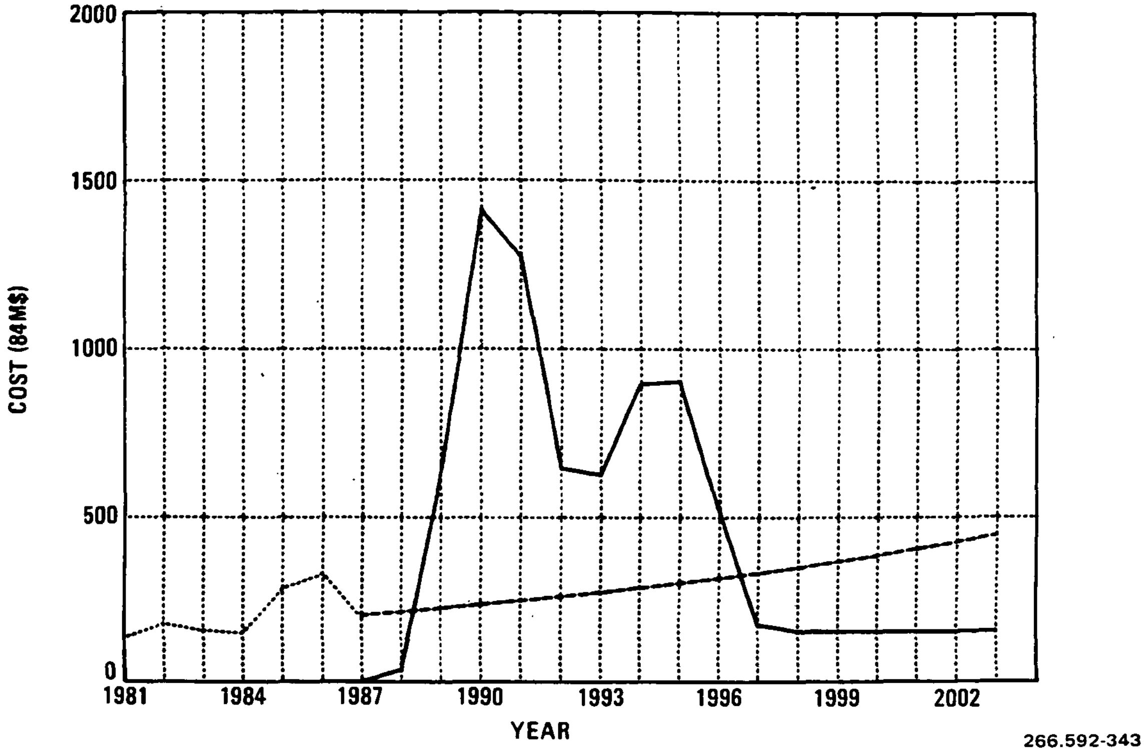

Figure 3-14. User Information Mission Set Funding - Planetary Exploration

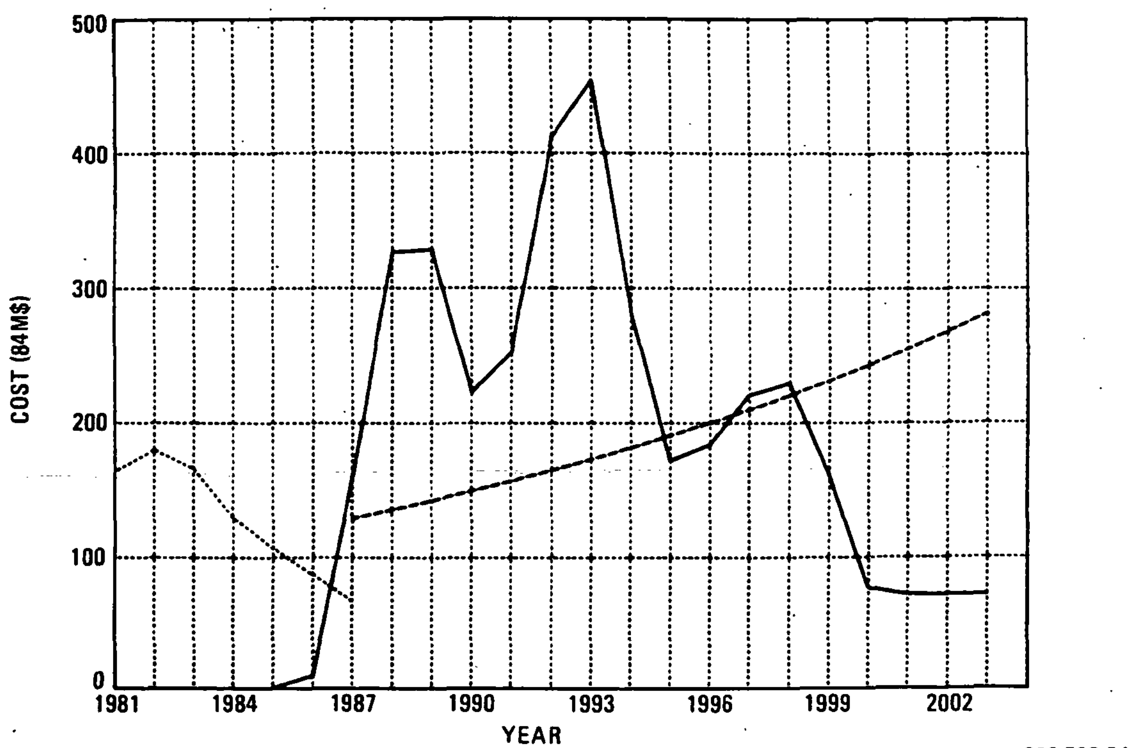

Figure 3-15. User Information Mission Set Funding - Solid Earth Observations

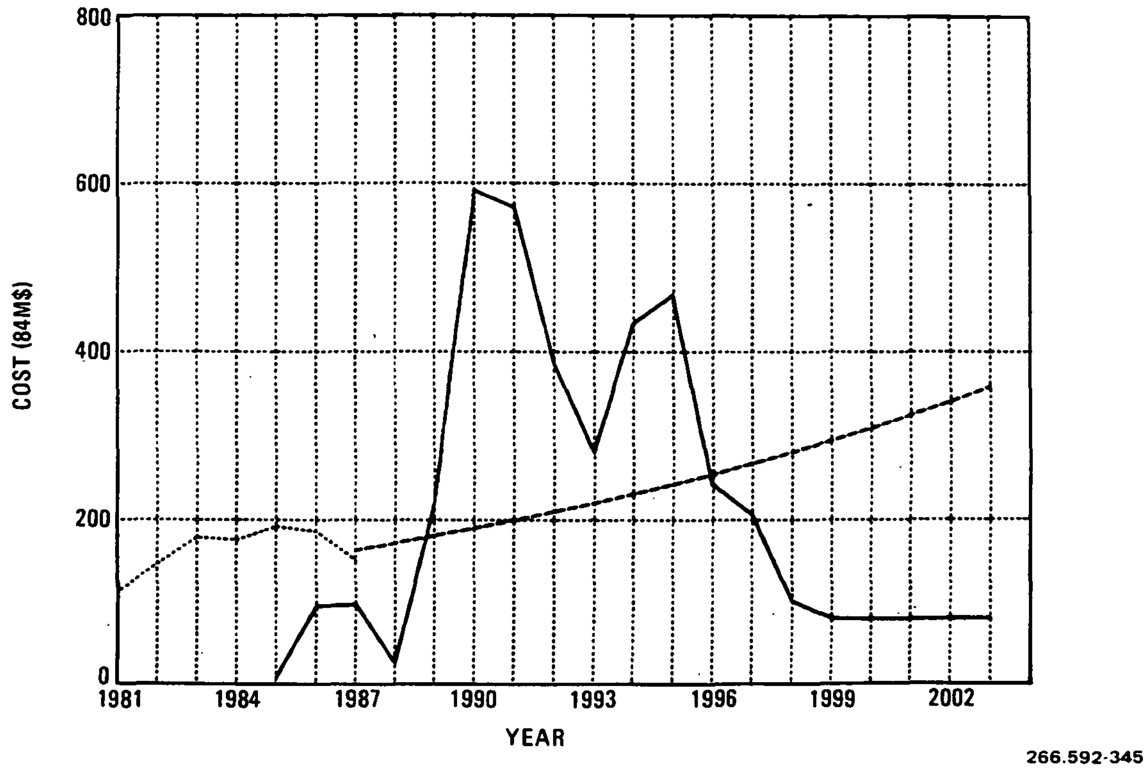

Figure 3-16. User Information Mission Set Funding - Environmental Observations

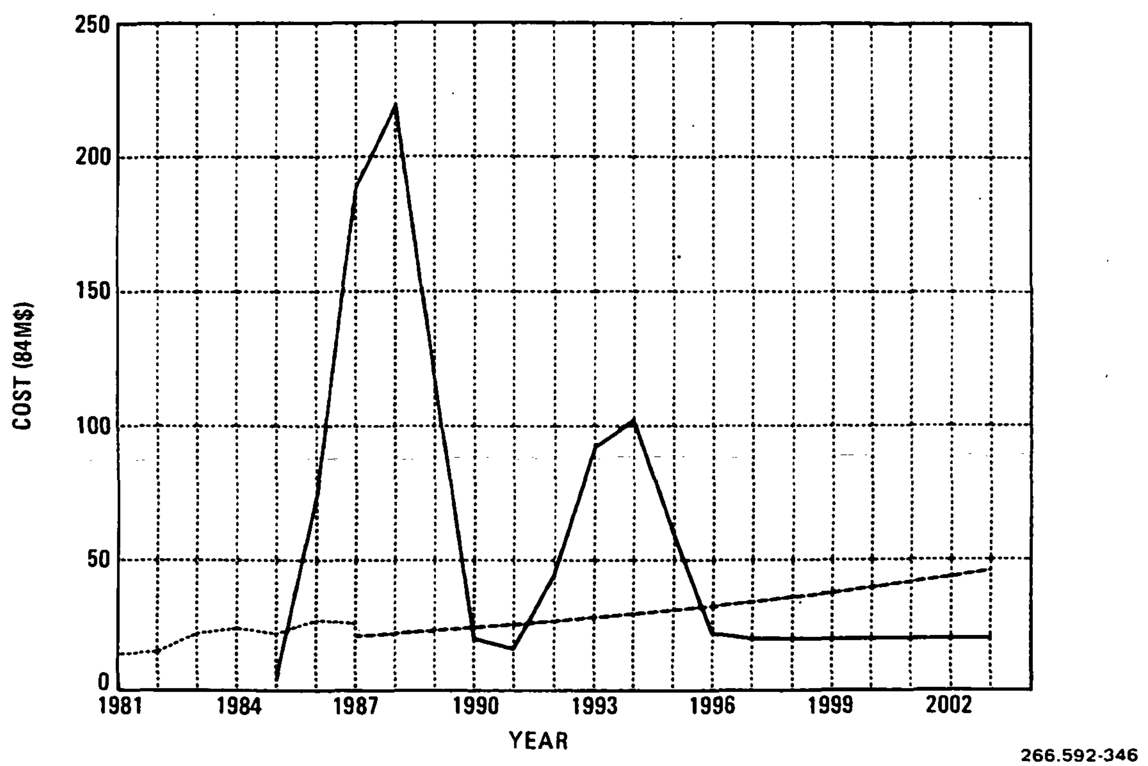

Figure 3-17. User Information Mission Set Funding - Life Sciences

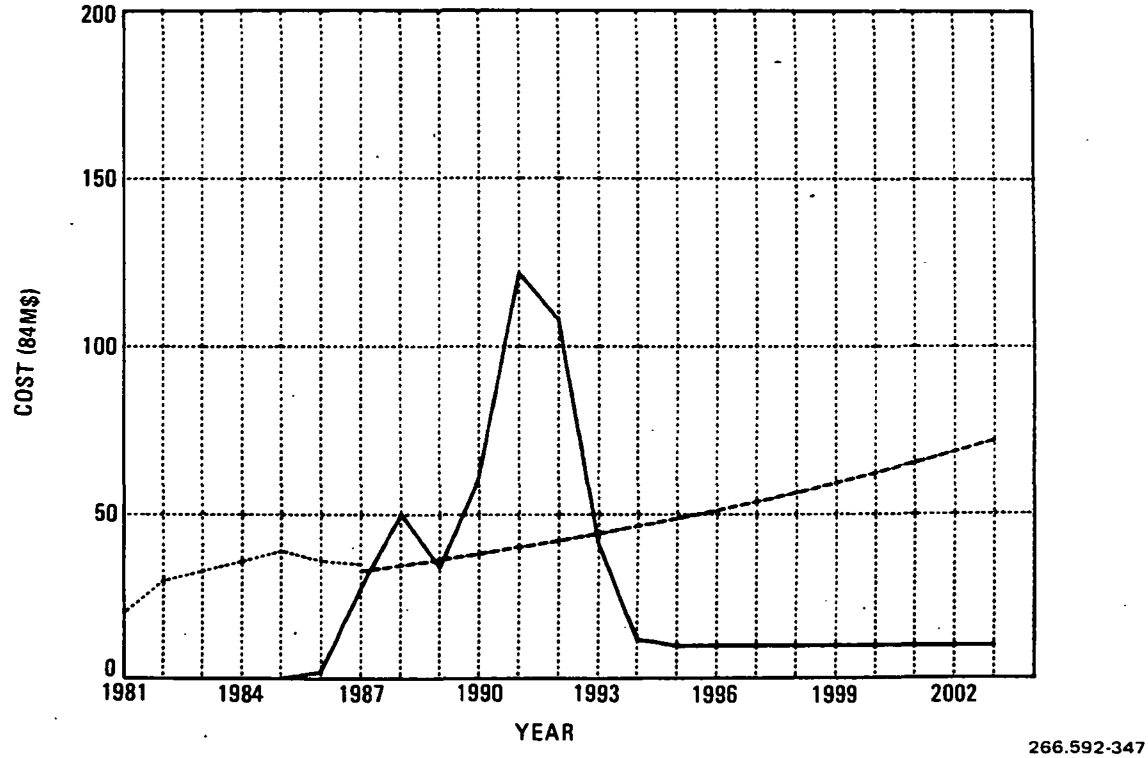

Figure 3-18. User Information Mission Set Funding - Materials Processing

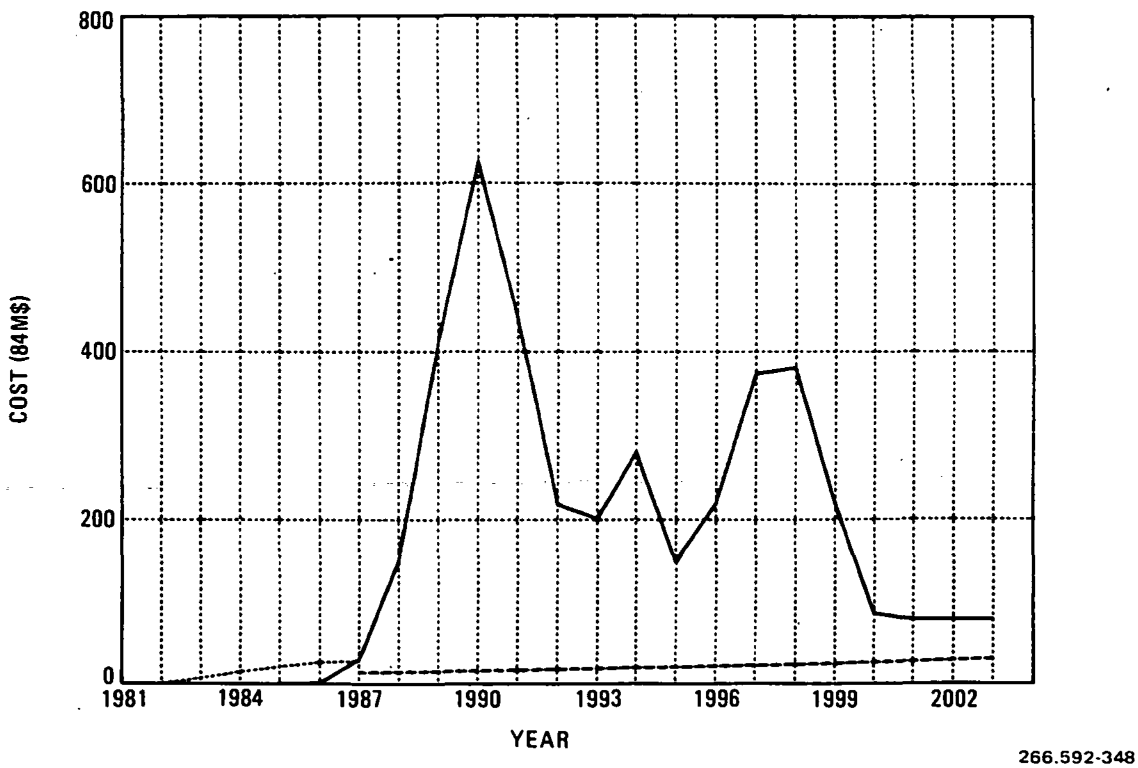

Figure 3-19. User Information Mission Set Funding - Technology Development

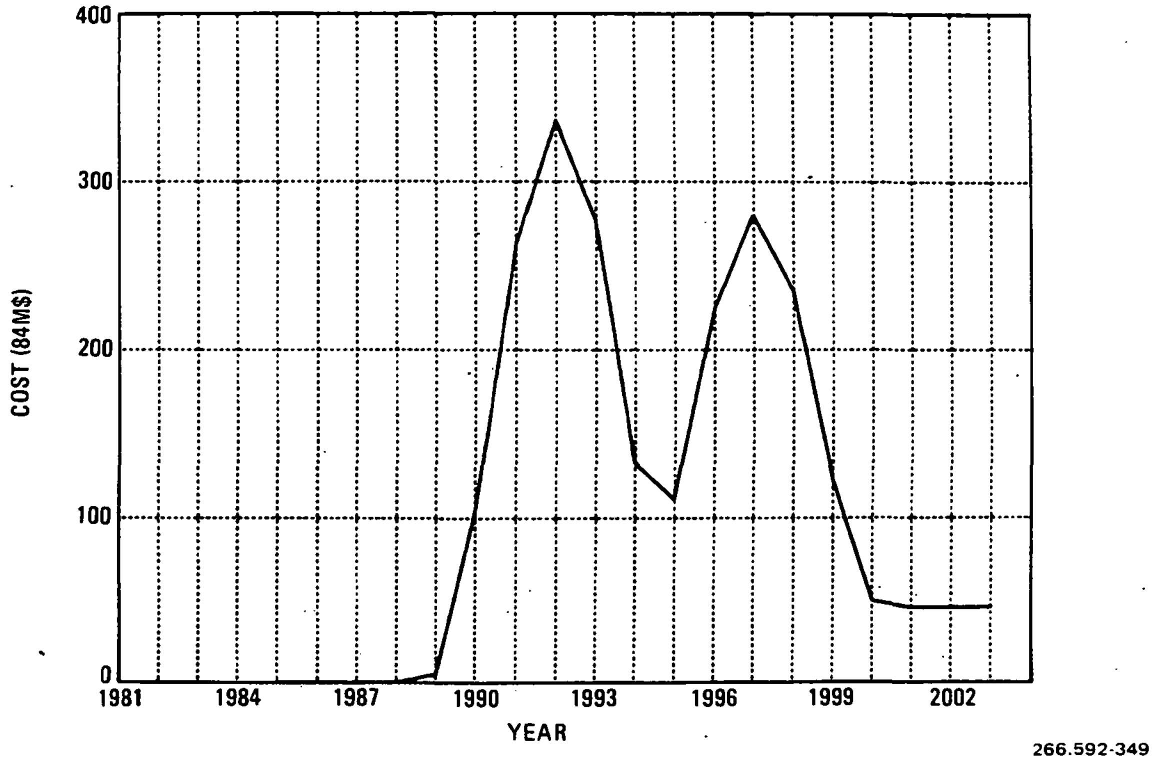

Figure 3-20. User Information Mission Set Funding - Space Operations - Manned GEO Mission

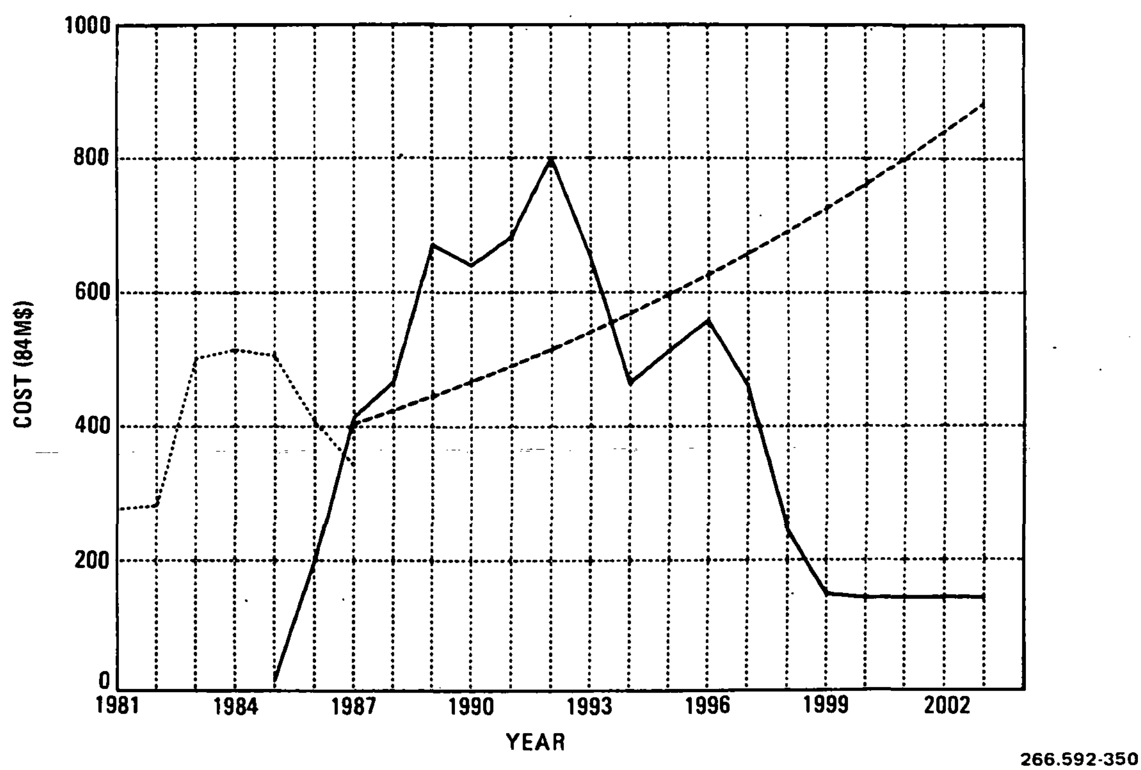

Figure 3-21. Baseline Mission Set Funding - Astrophysics

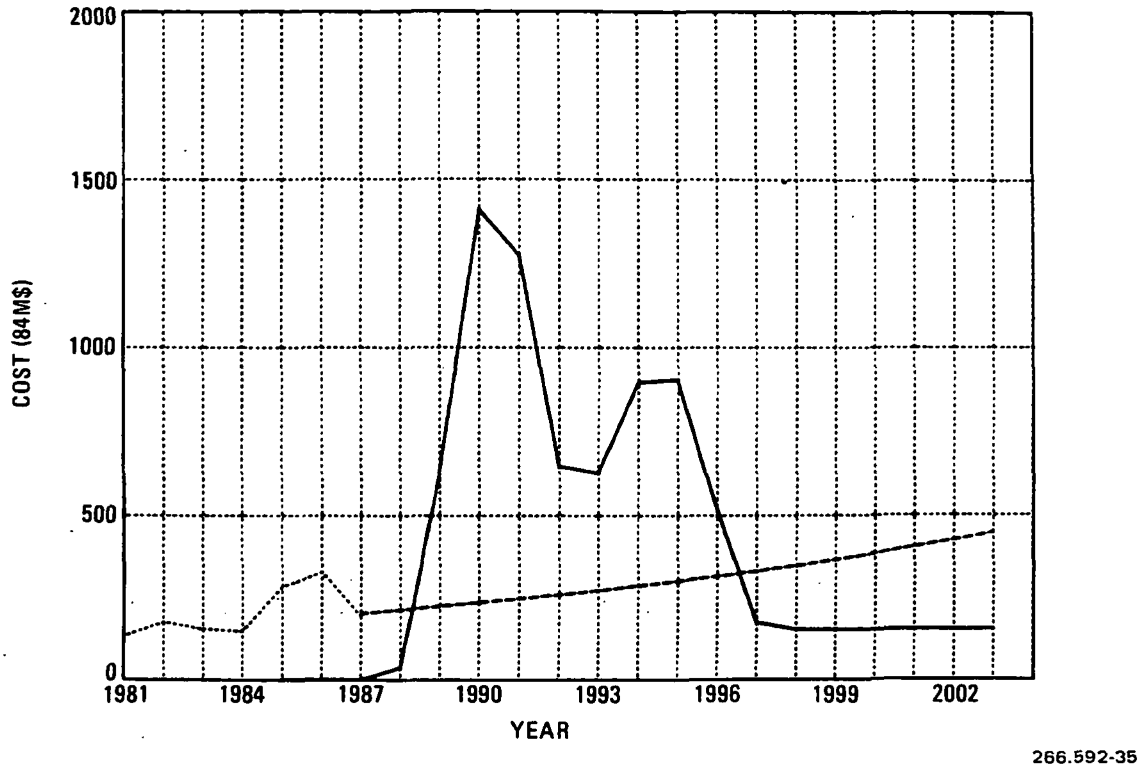

Figure 3-22. Baseline Mission Set Funding - Planetary Exploration

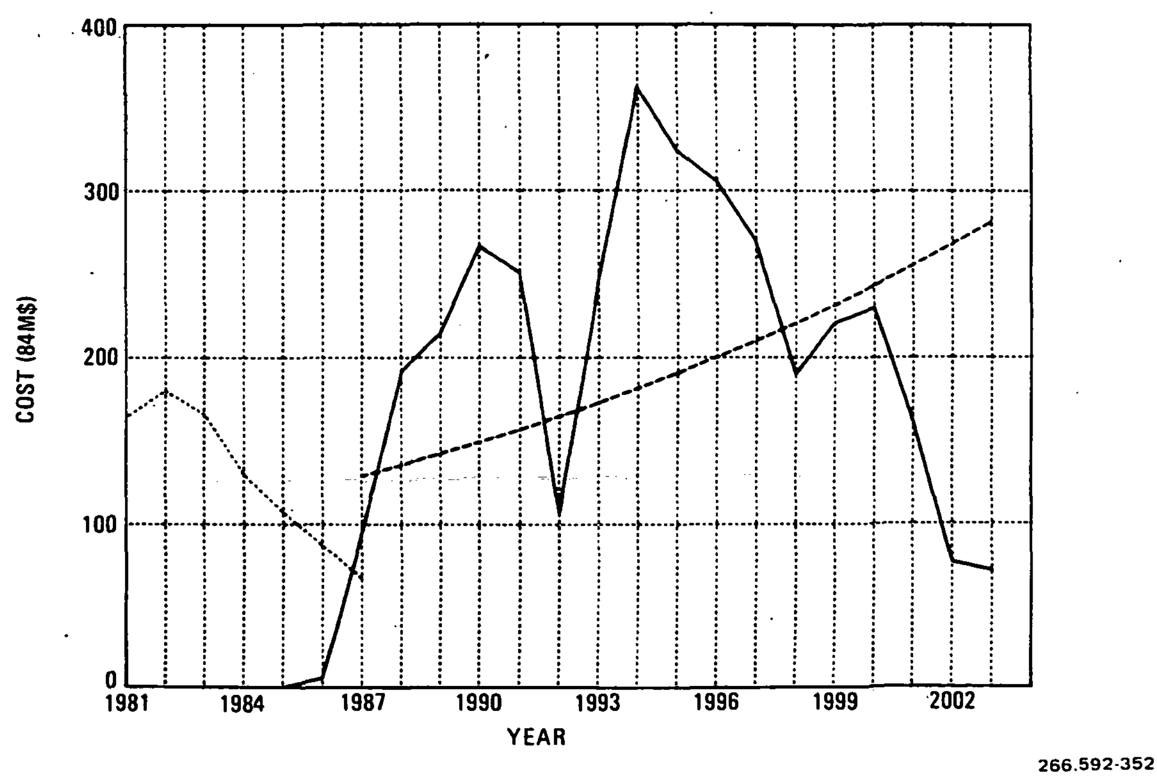

Figure 3-23. Baseline Mission Set Funding - Solid Earth Observations

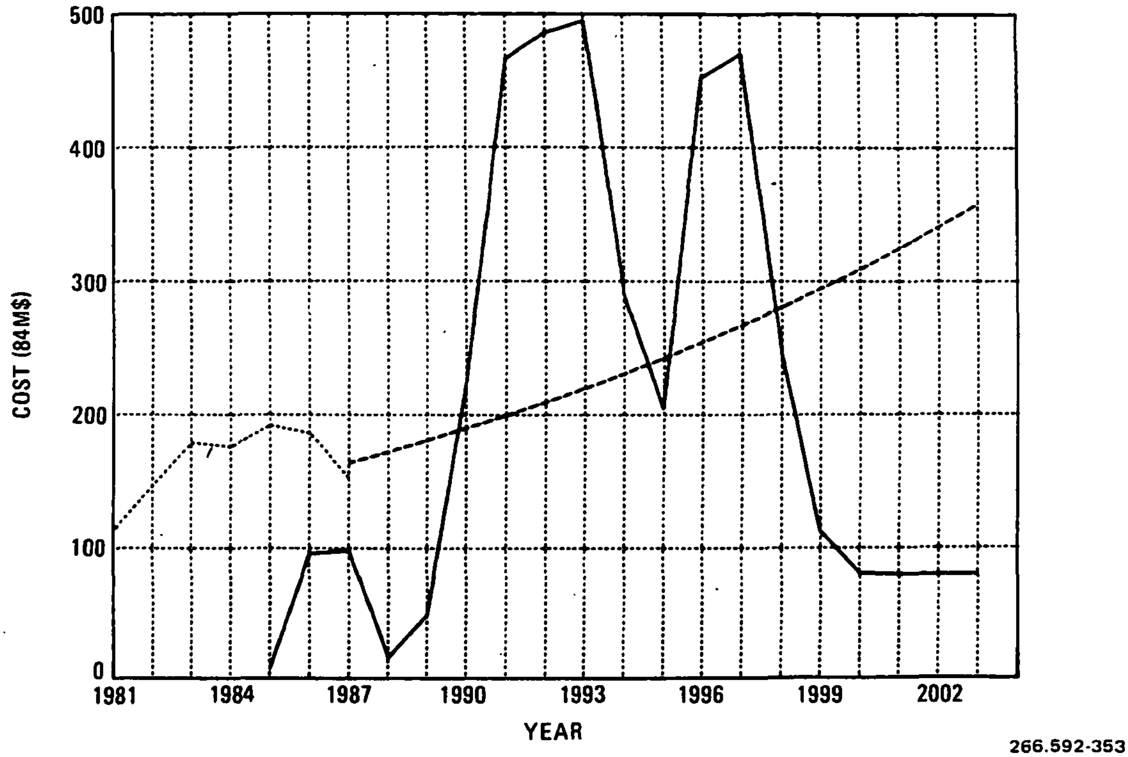

Figure 3-24. Baseline Mission Set Funding - Environmental Observations

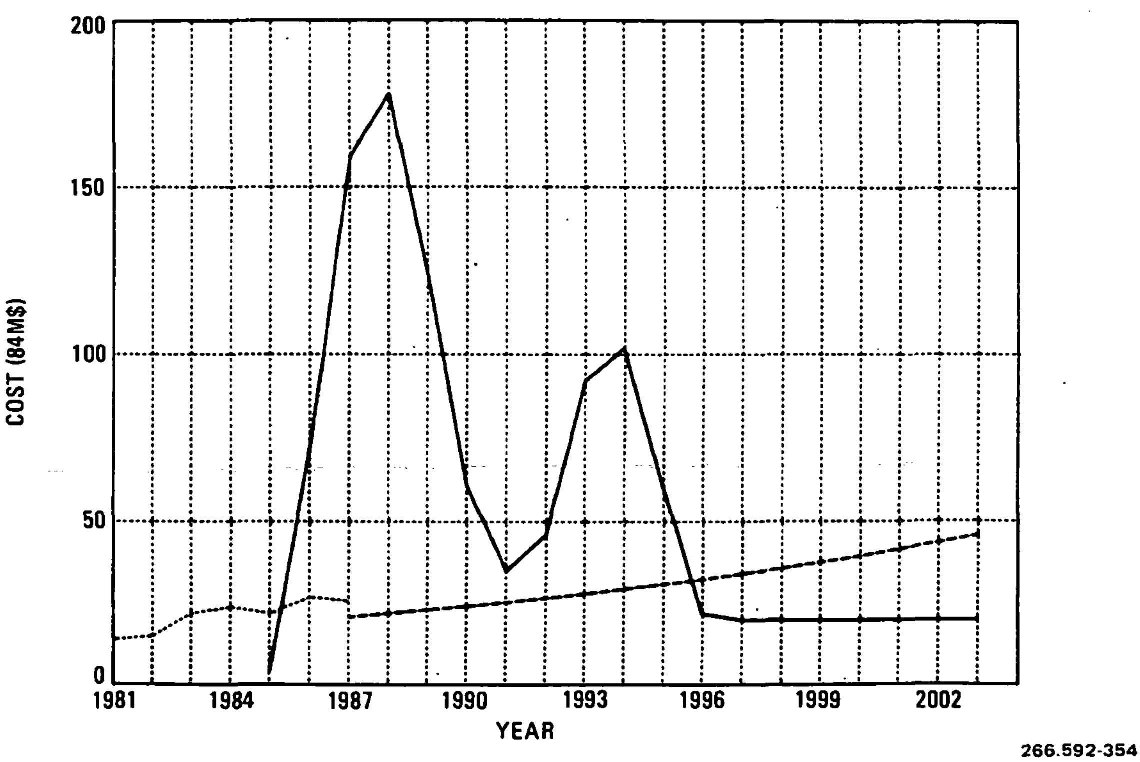

Figure 3-25. Baseline Mission Set Funding - Life Sciences

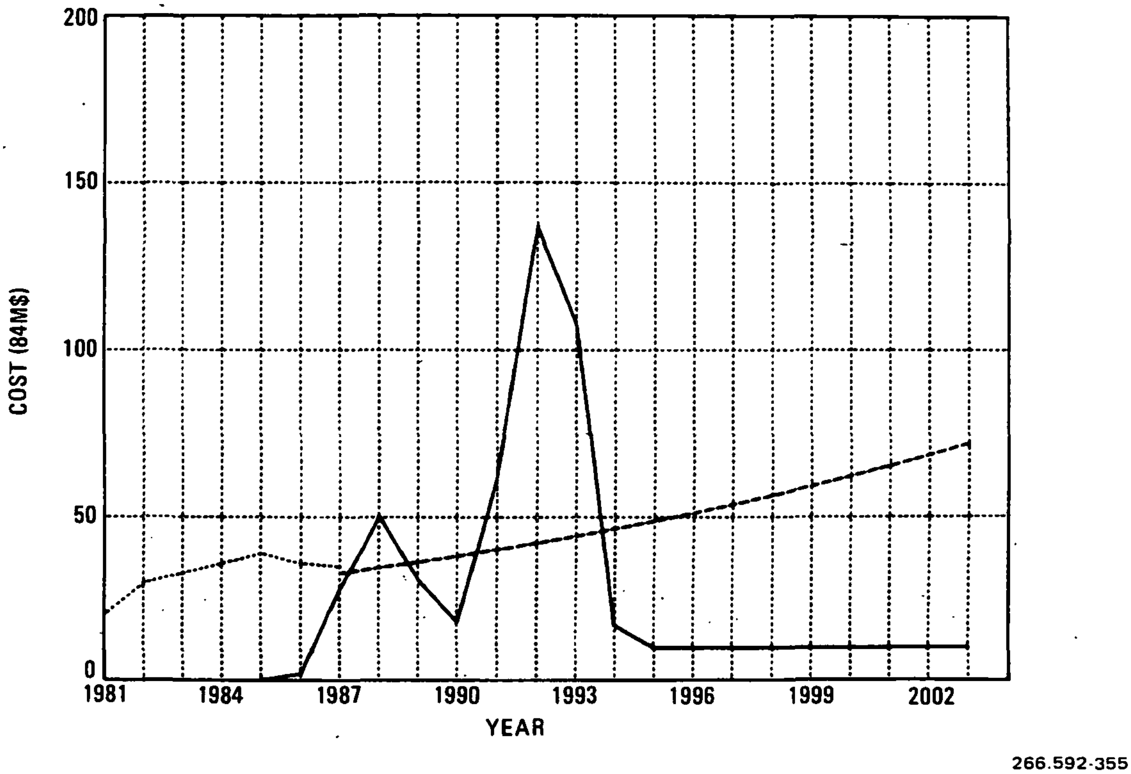

Figure 3-26. Baseline Mission Set Funding - Materials Processing

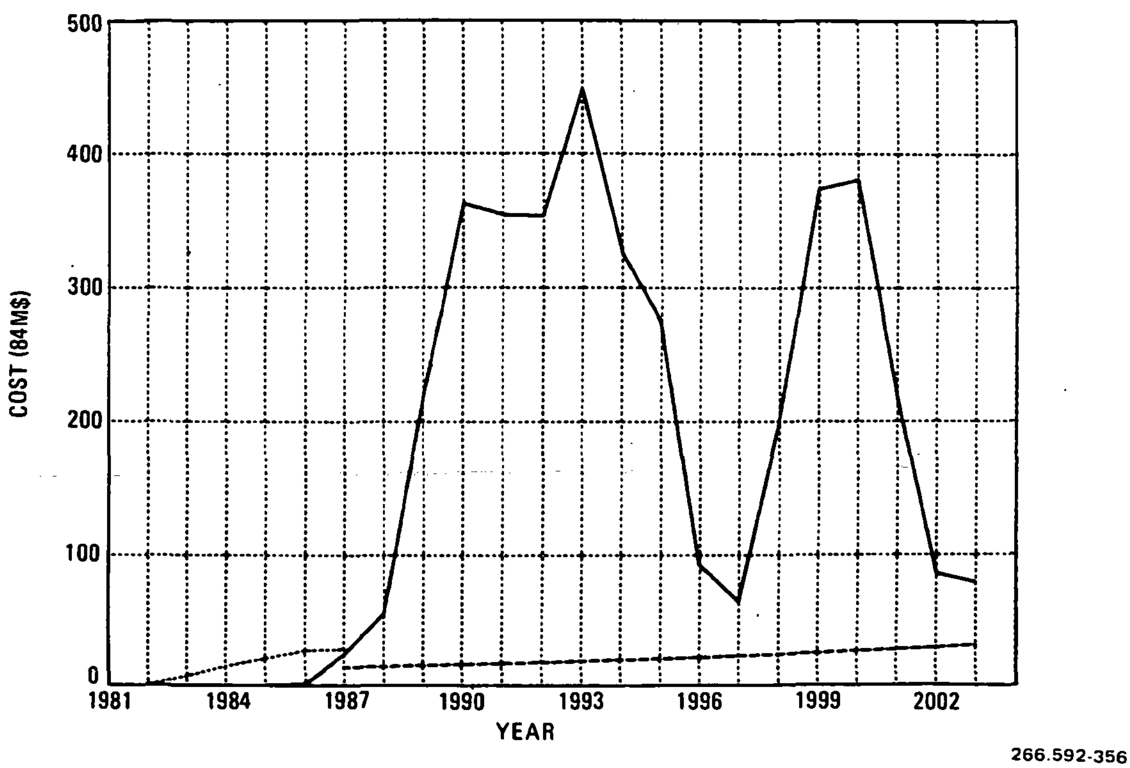

Figure 3-27. Baseline Mission Set Funding - Technology Development

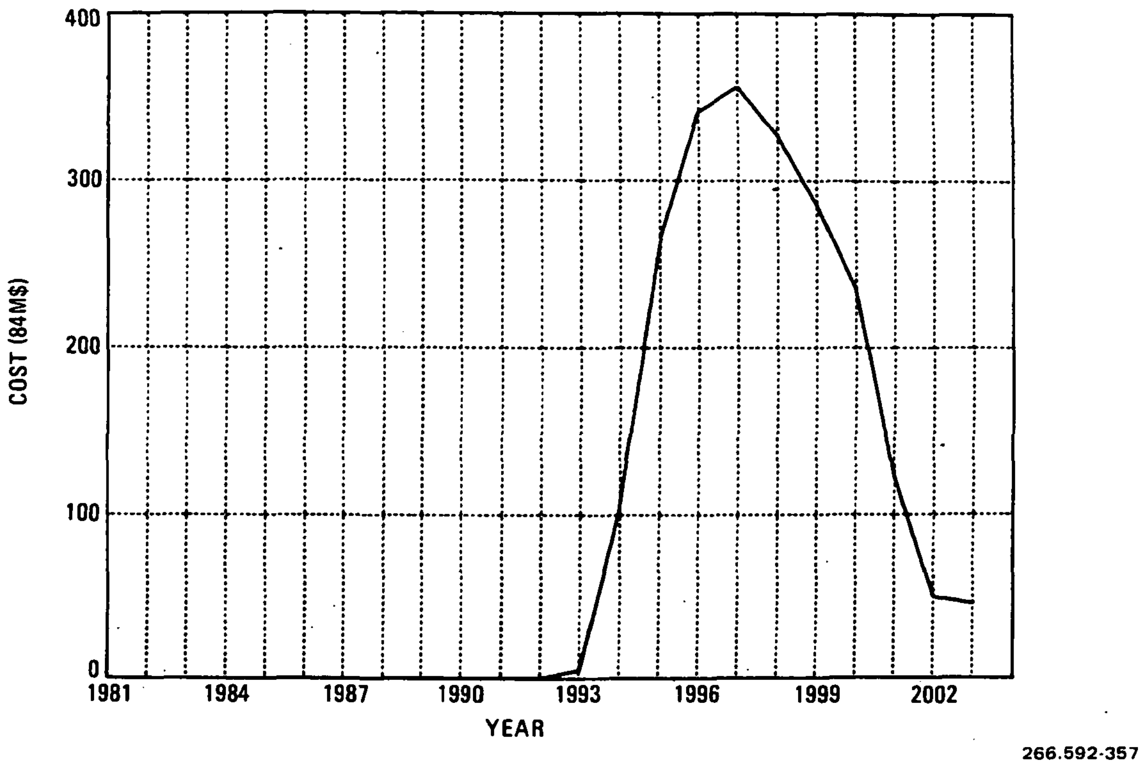

Figure 3-28. Baseline Mission Set Funding - Space Operations — Manned GEO Missions

3.3.4 PROGRAM FUNDING REQUIREMENTS. After Space Station development, hardware, and operations costs have been developed, they serve as input to the phased-funding model used previously for the mission set. The Space Station program funding profile is then combined with the station-attached mission set profile as shown in Figure 3-29 for the research station program. The Space Station development and hardware costs consist of about 40% of the total $15 billion research station program cost over the first 15 years. The NASA budget would require a peak-year funding requirement of almost $3 billion in 1989 for an initial research station operational in 1990. Once the station is fully operational, annual costs drop to about $500 million.

A combined research and operations Space Station would cost about 50% more to build and develop than the initial research station, and a small amount more per year to operate, as shown in Figure 3-30. The additional capability represented by the space-based OTV and a propellant transfer tanker would add an additional 30% to the cost of the development and hardware costs of the program. The peak-year funding requirement, however, remains at almost $3 billion because of the evolutionary phase-in process of the operational portion of the station. Total funding requirements over the 15-year span are 40% higher for the combined station than for the initial research station.

Figures 3-31 and 3-32 show the effect of the respective Space Station programs on the NASA budget. The NASA base includes funding for STS development, all Aeronautical Research and Technology, construction of facilities, and management and administration (R&PM), etc.

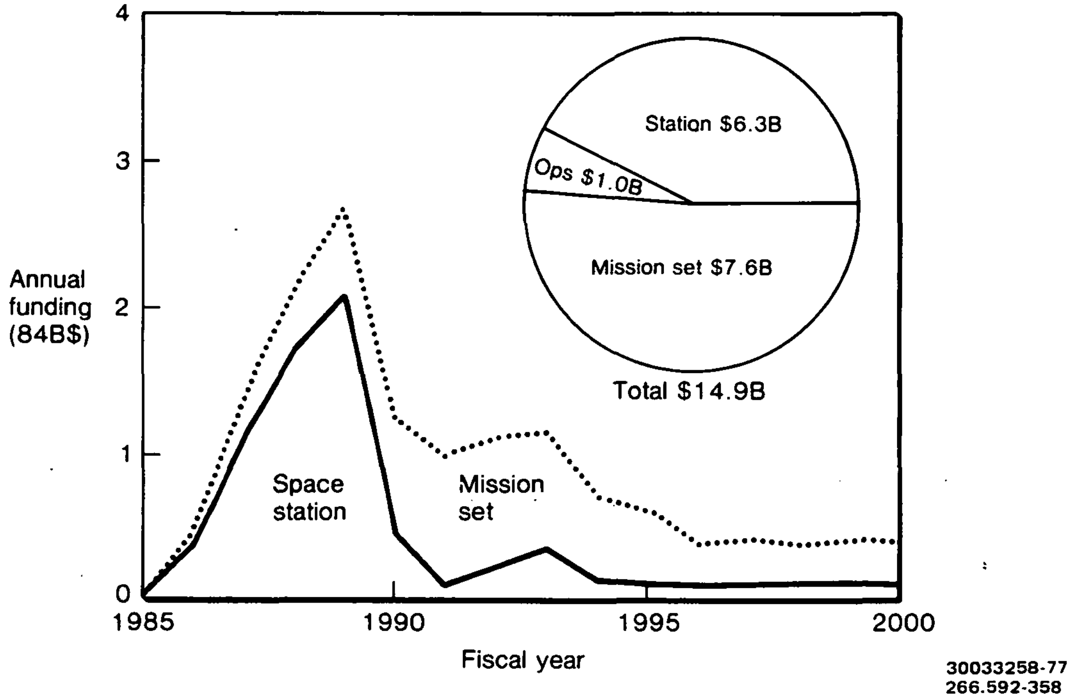

Figure 3-29. Research Space Station Program Funding Profile

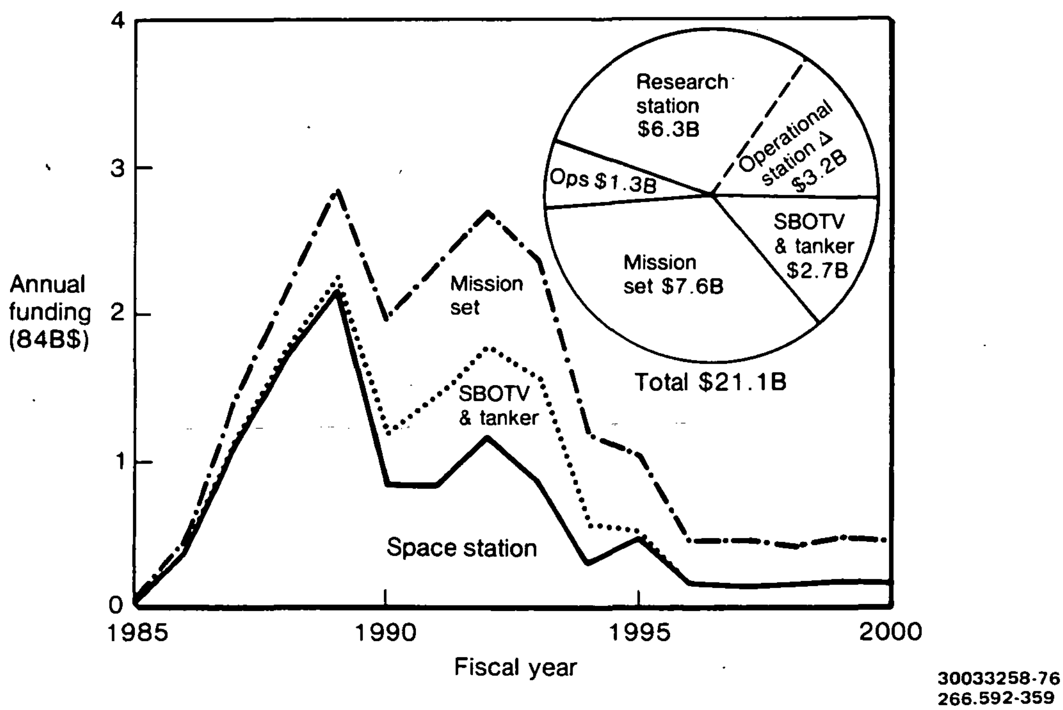

Figure 3-30. Combined Research and Operations Space Station Program Funding Profile

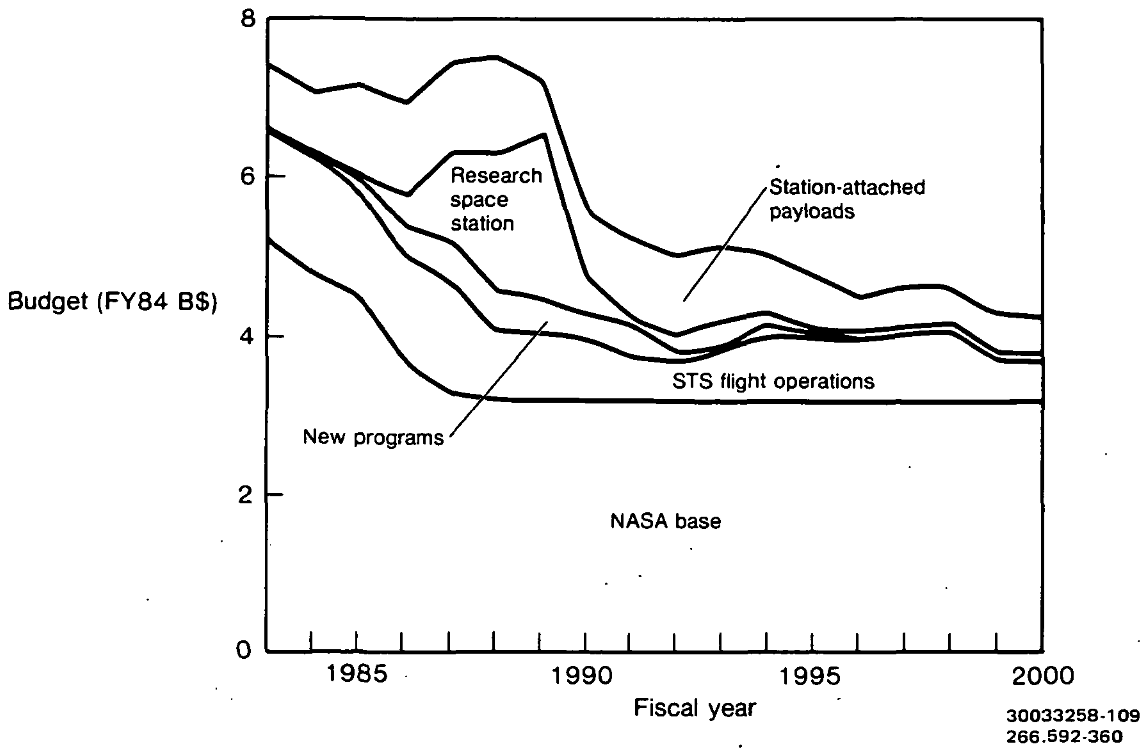

Figure 3-31. NASA Budget Profile (Research Station and Station-Attached Payloads)

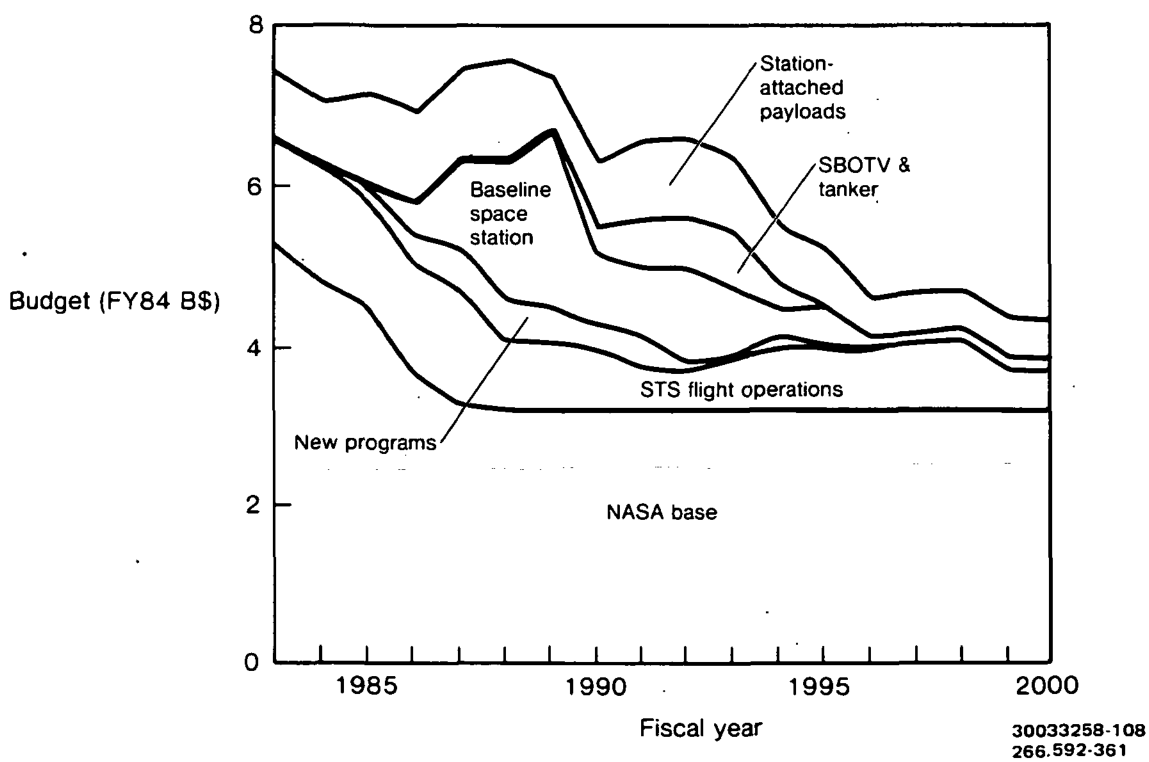

Figure 3-32. NASA Budget Profile (Baseline Station and Station-Attached Payloads)

The Shuttle flight operations portion consists of the net cost to NASA after reimbursements from commercial and DoD users in accordance with the STS traffic model shown in Table 3-6. Funding for fiscal years 1983-1987 is taken from the FY 1983 NASA budget, while funding for 1988-1989 is calculated under the assumption that the flight rates in these years will be the same as that in 1990.

New programs include a Shuttle-based TMS, a fifth orbiter, two space platforms, and construction of ground facilities.

The Space Station funding includes development and production of hardware and ground and flight operating costs, while the SBOTV and tanker funding includes two space-based OTVs and two proplellant transfer tankers. The station-attached mission set is used as a representative mission set, to show total station-related costs for comparative purposes. Both Space Station program funding profiles reveal peak-year funding under $8 billion. The major funding difference between the two programs occurs in the early 1990s, when the operational capability is phased in. During these years, annual funding with the baseline station program is under $6.5 billion, while funding with the research station is about $5 billion per year. Both programs show an annual funding level of about $5 billion in the out years.

Figures 3-33 and 3-34 show the budgetary effects of including all missions identified in the baseline mission set. Peak-year funding exceeds $8 billion under either program, while out-year funding levels off at $6 billion. Acutal NASA funding of experiements and spacecraft will probably lie somewhere between the current funding level and the level necessary to support the full baseline mission set.

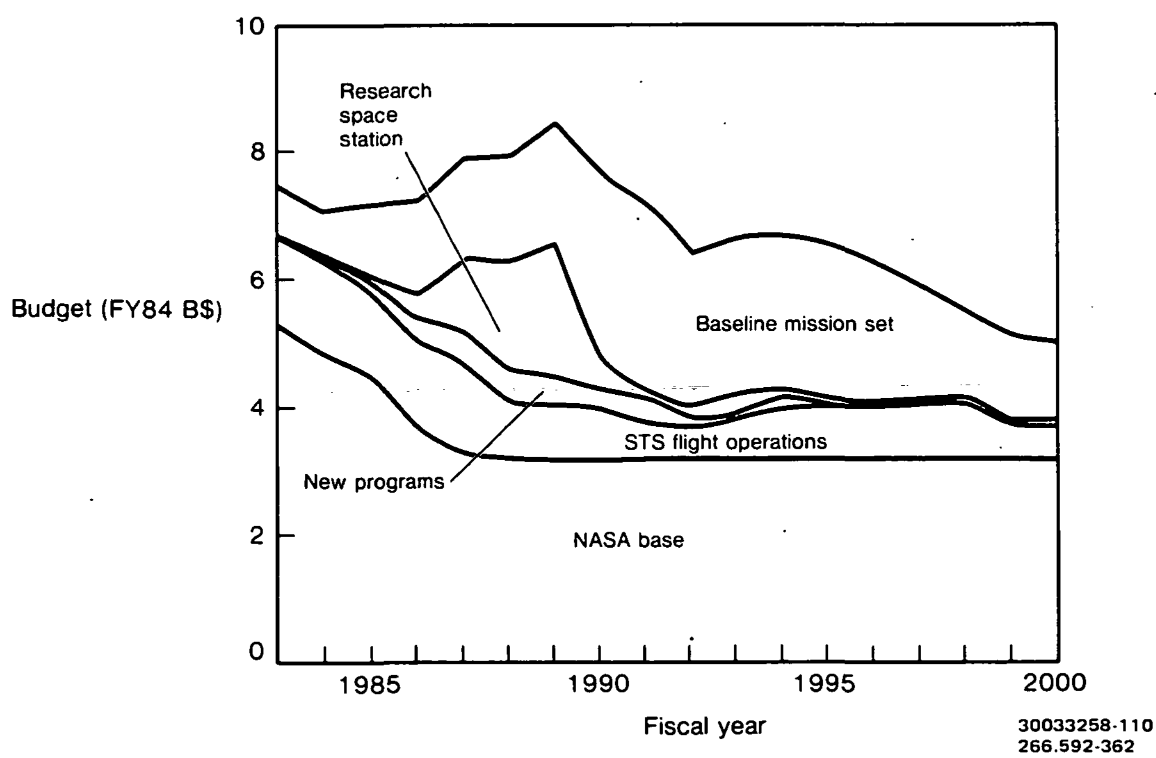

Figure 3-33. NASA Budget Profile (Research Station and Full Mission Set)

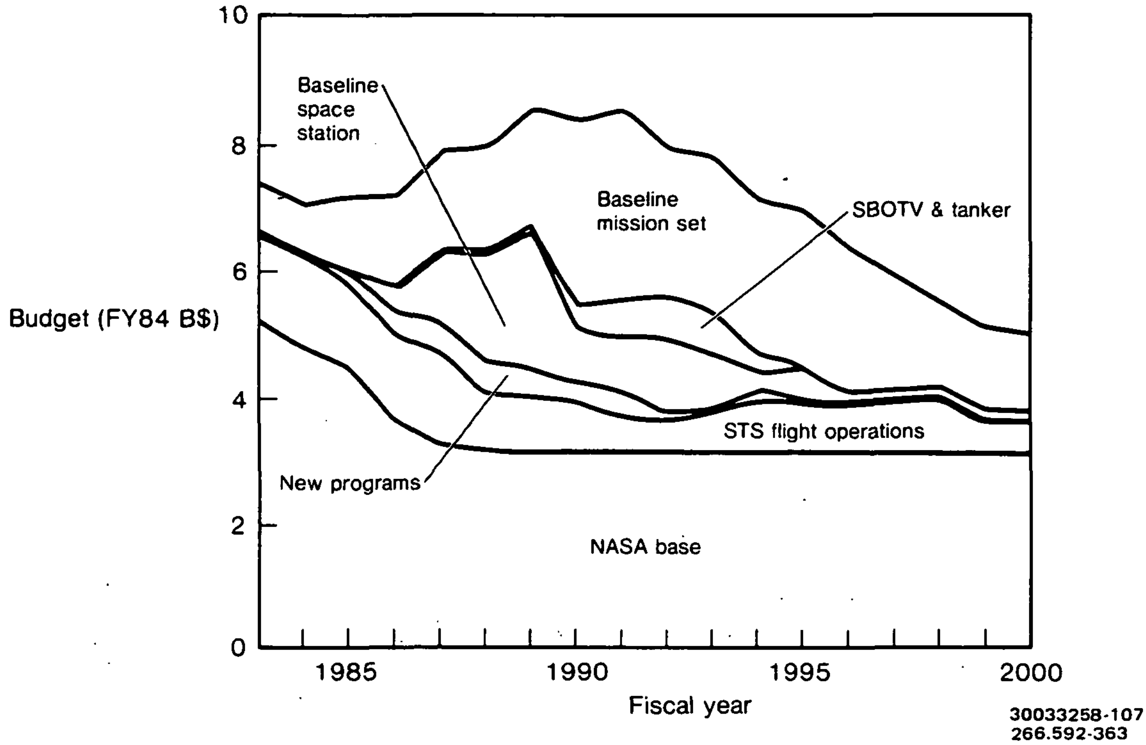

Figure 3-34. NASA Budget Profile (Baseline Station and Full Mission Set)

3.3.5 ECONOMICS BENEFITS CASH FLOW. Cost and benefits may be examined from the viewpoint of a classical cash flow problem. Examining these economics benefits "cash flow" can be instructive even though all of the economic benefits are obviously not necessarily available as actual revenues since many are in the form of cost savings or value added. Nevertheless, this information will provide an indication of the break-even period in terms of the global economic point of view and is certainly useful for comparative purposes.

The first analysis, an undiscounted cash flow comparison of the baseline (or combined) station to either a research station or a SBOTV station alone, is shown in Figure 3-35. Although negative cash flow for the research station is less than $6.5 billion, the payback period is over 30 years. With an additional $3.5 billion negative cash flow for the SBOTV station, the payback period is reduced to just over 17 years. The baseline combined station requires a maximum negative cumulative cash flow of $11 billion and has a payback period of 16.7 years.

Figure 3-36 shows a comparison of the cash flows of the three station options discounted at 7%, historically an average nominal discount rate. The SBOTV station cash flows were shifted four years so that all cash flows would be discounted back to the same base year, 1984.

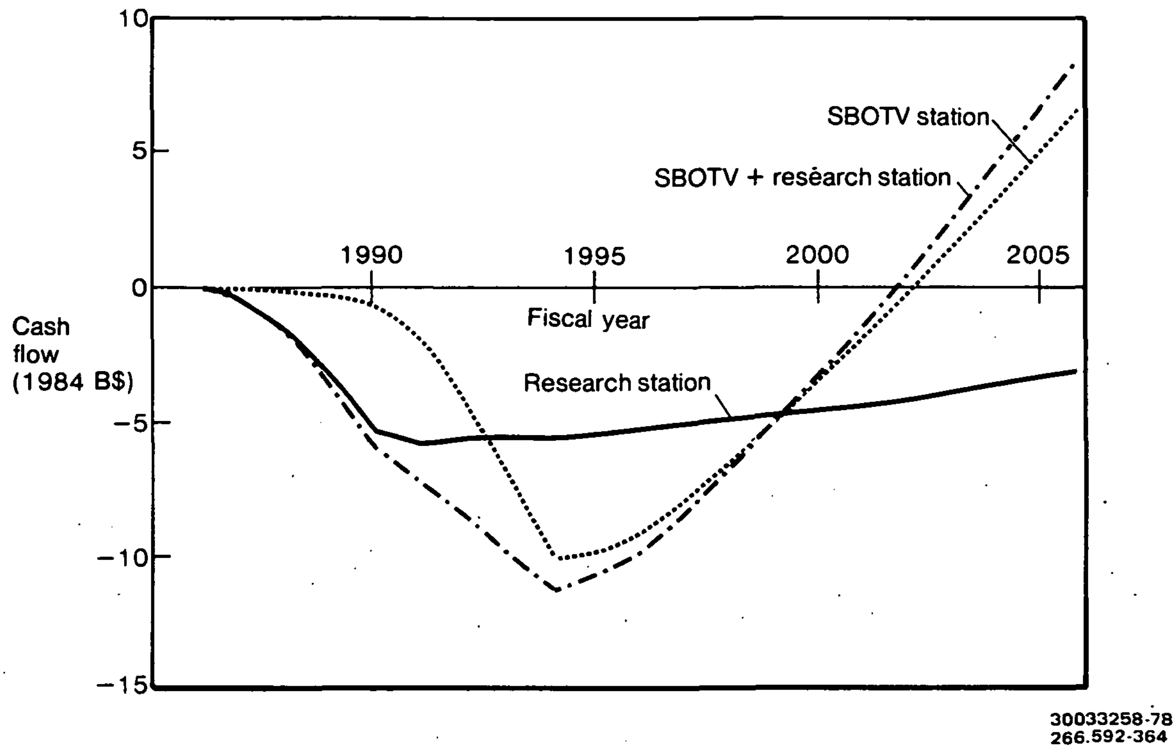

Figure 3-35. Economic Benefits Cash Flow, Undiscounted

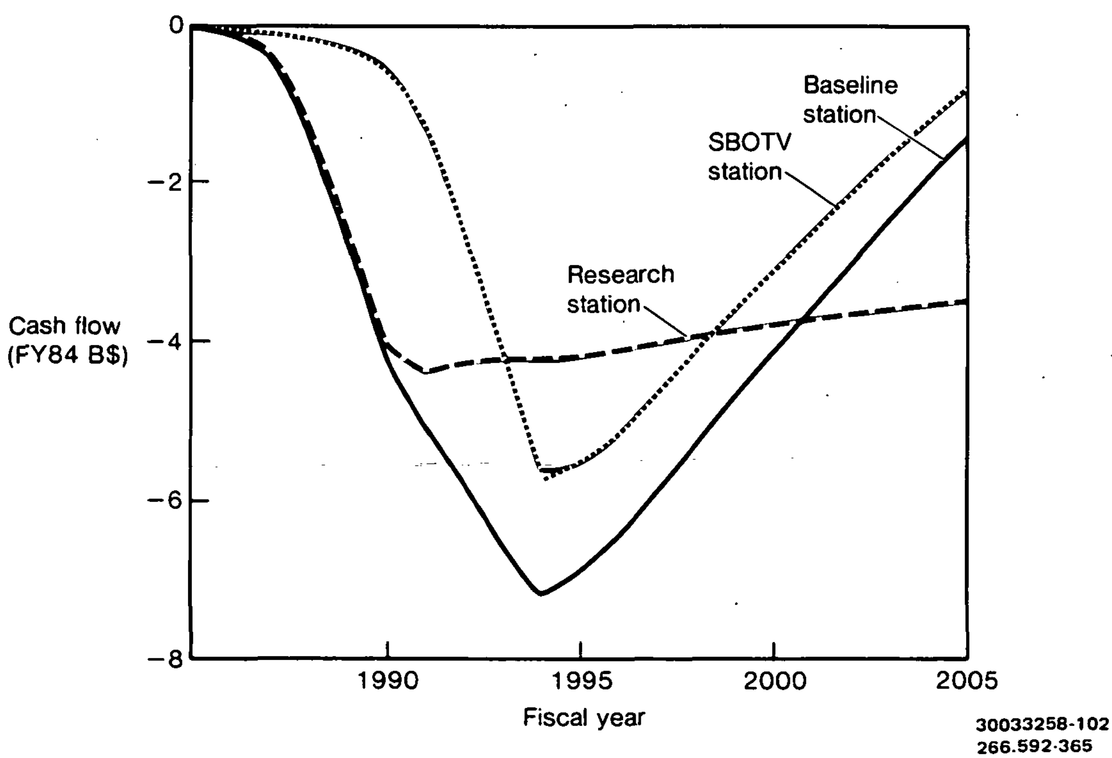

Figure 3-36. Economic Benefits Cash Flow, Discounted 7%

Based on near-term economics alone, a SBOTV station returns more on the investment than the other stations. However as noted earlier, the long-term benefits of a research station can be relatively unlimited. The combined station can give both the near-term benefits of the SBOTV operations and the long-term benefits of space research without requiring a great deal more funding.

Figure 3-37 shows the cash flows of the baseline combined space station and a combined station that evolves from a SBOTV operations station in 1990 to a station including research in 1994 (i.e., reversing the order of development). This approach to the combined station provides the revenues of the SBOTV operations in the early years and the addition of the research portion in 1994. This approach cuts almost two years from the payback period of the baseline station. Figure 3-38 shows that the maximum cumulative discounted cash flow delta between the two combined-station scenarios is negligible and the net present values are within $500 million. The economic factors are from this point of view, not conclusive. The schedules of the OTV, tanker, and technology demonstrations, however, need to be examined in detail to determine the feasibility of the 1990 IOC for the space-based OTV.

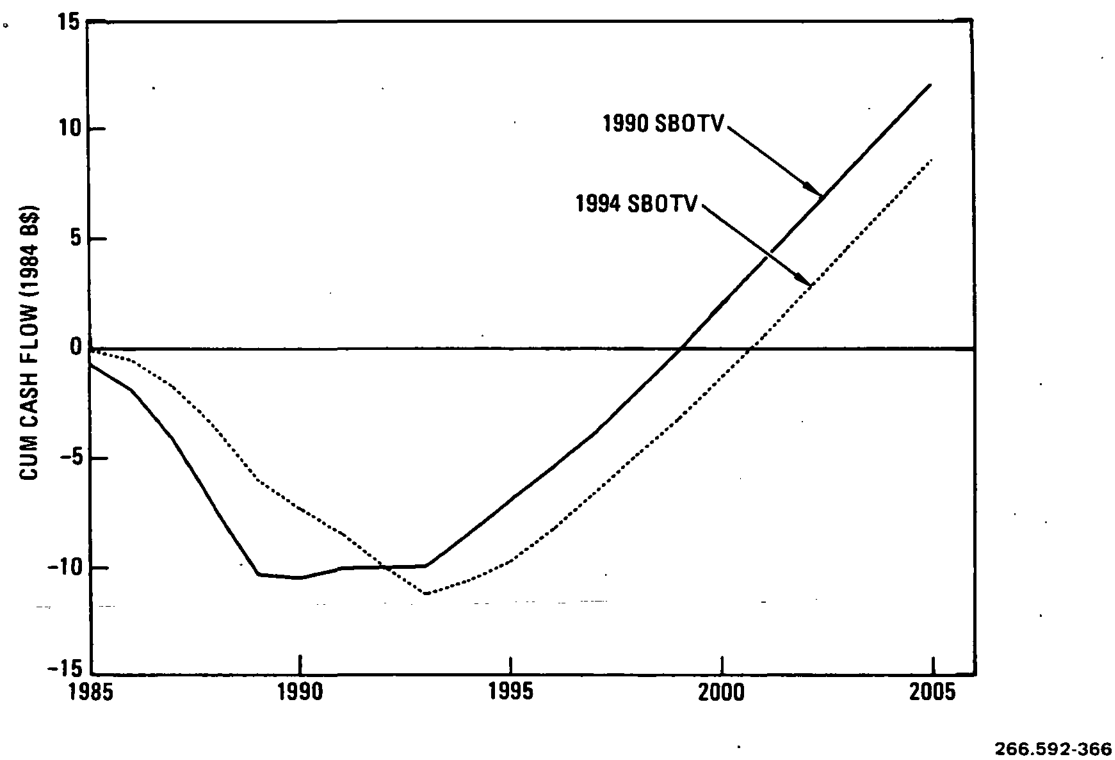

Figure 3-37. Economic Benefits Cash Flow, Undiscounted (Early Space Based OTV Availability)

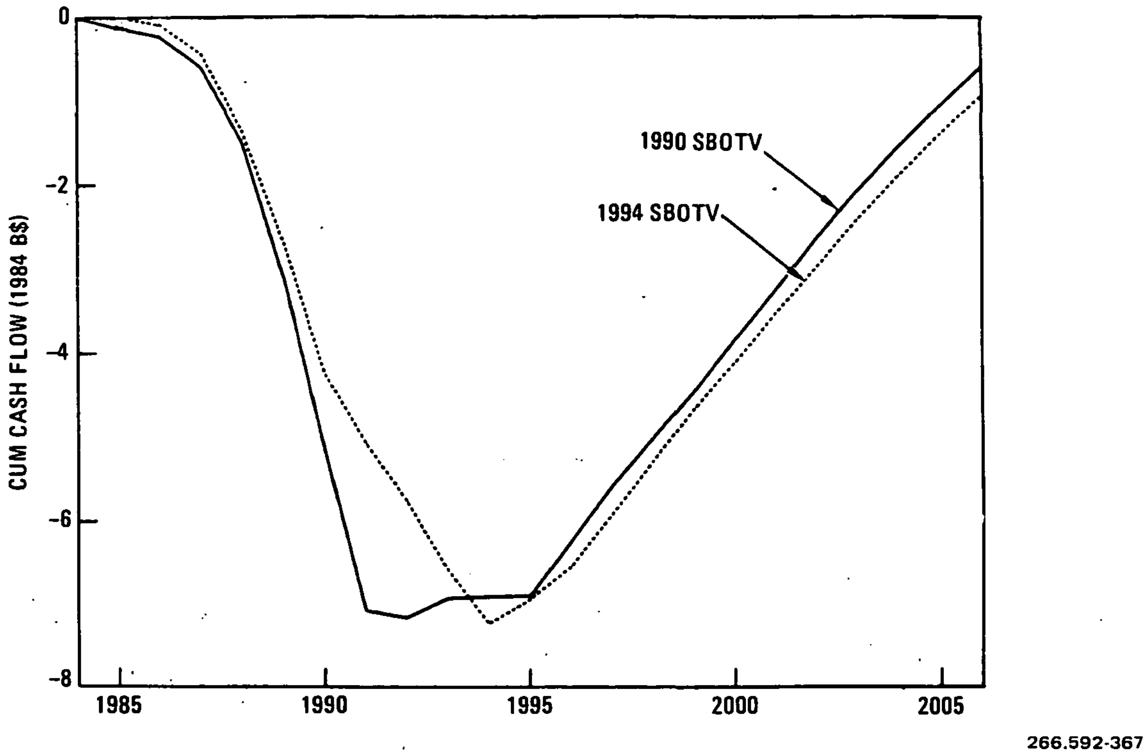

Figure 3-38. Economic Benefits Cash Flow, Discounted 7%
(Early Space Based OTV Availability)

SECTION 4

PROGRAMMATICS AND BUSINESS OPPORTUNITY ASSESSMENT

4.1 INTRODUCTION

Exploration of options for partnership between the government and industry in a Space Station program was a major study task and is outlined in Figure 4-1.

Analysis of government requirements and private sector investment criteria provided the foundation for development of program alternatives designed to meet public and private requirements. Joint Endeavor Agreements and formation of a "Space Development Corporation" were shown to have potential for attracting private investment in a Space Station enterprise. The Space Station Prospectus (Appendix I) was developed to demonstrate how an even greater degree of industry involvement might be achieved.

4.2 SPACE STATION INVESTMENT CRITERIA

The economic benefits and costs described in the previous two sections are important not only in assessing the value of a Space Station, but also in determining who should pay for such a facility. As our activities in space have evolved from purely exploratory and security-oriented programs to more diverse projects involving commercial interests, fundamental investment criteria have changed. Unlike major undertakings of the past, such as Project Apollo and Skylab, the Space Station program will probably be heavily influenced by economic and commercial interests from its inception. The Space Shuttle, which was designed partly in consideration of its commercial potential, differed from Apollo and Skylab in this regard, but economic and commercial factors appear likely to exert much greater influence on Space Station development.

Of most obvious concern is the impact of economic factors on Space Station design. In the extreme, a Space Station program unbounded by any economic constraints would result in the establishment of a facility quite different from what real-world conditions would create. Economic concerns of far greater subtlety, however, can also have a profound impact on design strategy. A shift in emphasis from low-cost to high-return, for example, could dictate a complete reversal in the prioritization of the Space Station architectural elements, as illustrated in Figure 4-2. Since past Space Station studies have emphasized technological achievability and low initial cost, the relatively complex and costly space-based OTV function has traditionally been viewed as a later, lower-priority Space Station development. Hence it has been generally assumed that the initial Space Station will be a relatively modest research and production facility. If near-term economic return becomes the chief objective, however, then the potentially lucrative OTV function has to be considered an early, high priority goal.

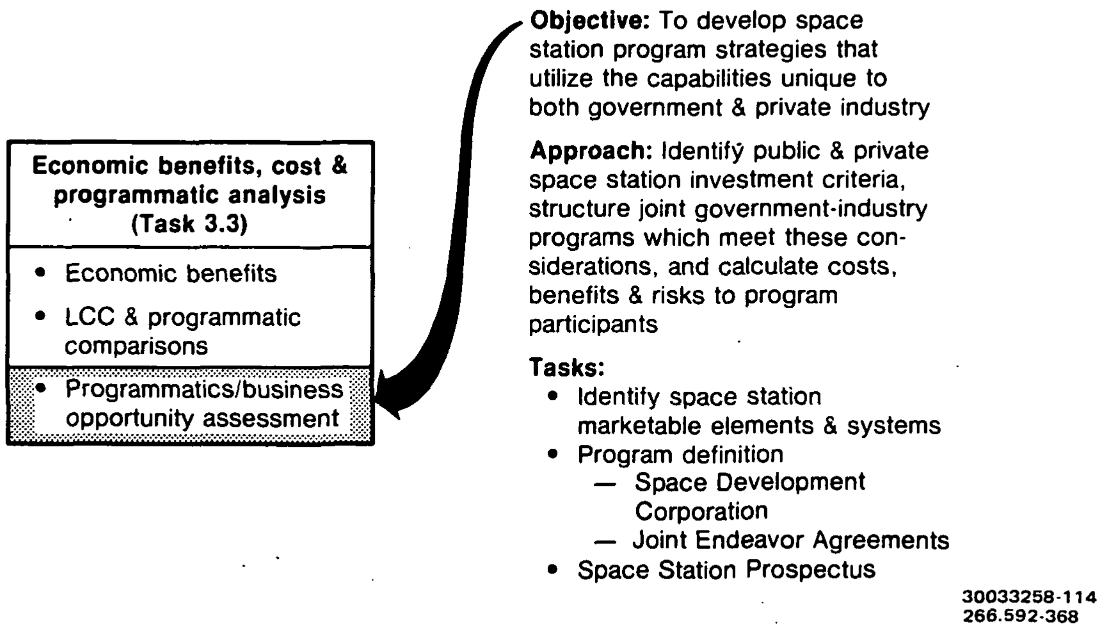

Figure 4-1. Programmatics/Business Opportunity Assessment

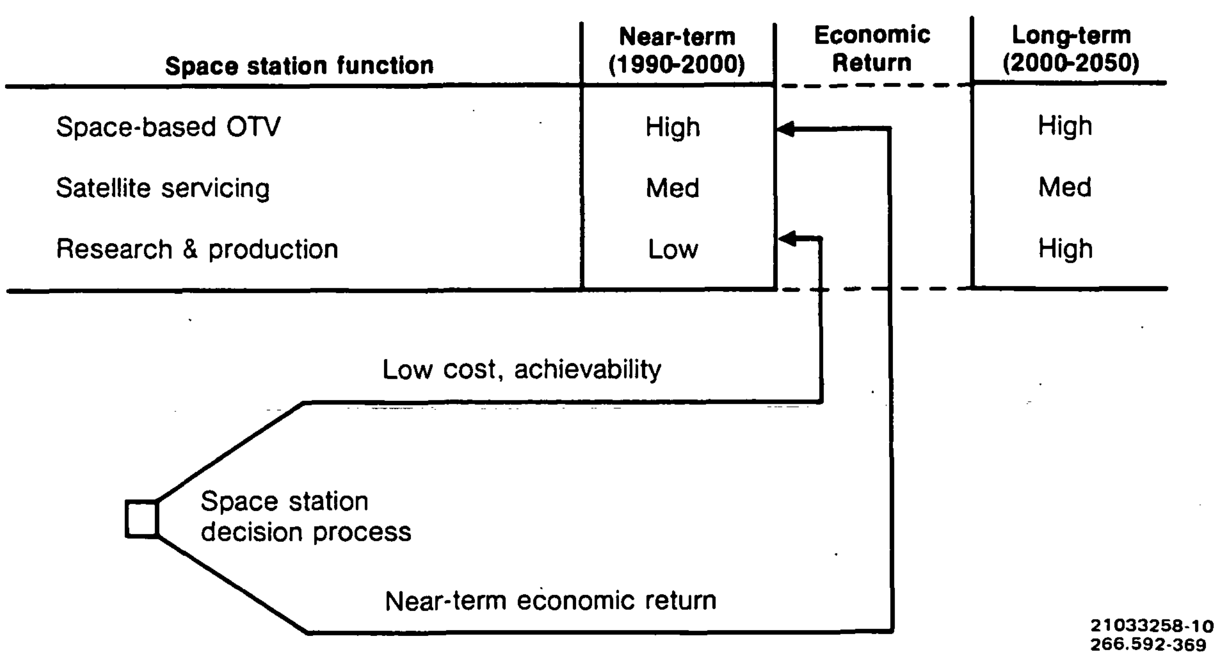

Figure 4-2. Impact of Economic Considerations on Space Station Decision Process

Introduction of economic considerations dealing with commercial utilization raises an additional issue that is of fundamental interest: How to divide Space Station costs and benefits among government and industry partners. Planning criteria that typically characterize public programs must be modified to account for private-sector interests, so a joint public-private Space Station program could differ substantially from one that is strictly public in nature.

4.2.1 GOVERNMENT (PUBLIC SECTOR) REQUIREMENTS. As discussed in the previous chapter, government economic planning criteria are influenced primarily by fiscal considerations, i.e., budgetary constraints. For this reason economic decisions are shaped more by cost factors than by economic benefits, which explains in part the prevailing emphasis on affordable systems. The promise of economic payback is not a major issue, perhaps because the government cannot realize an economic return on its projects, with possibly the sole exception of taxation. Instead, the value of government projects is usually measured in noneconomic terms such as social benefit, with occasional reference to gross economic indicators such as inflation, unemployment, or GNP.

In the absence of a clear-cut profit motive, it is sometimes difficult to distinguish what determines an acceptable funding profile for a given program. This is especially true of space projects, which are not directly utilitarian, as in the case of highways, nor humanitarian, such as social welfare programs. The social benefits of the space program are more commonly linked with ideals that are less tangible (and less universally accepted), such as national prestige, scientific gain, or technological spin-offs.

Economic analysis has had a limited role in developing these types of programs - limited to assuring that program costs do not exceed certain envelopes of acceptability. These boundary conditions on cost are generally established by noneconomic considerations, although, as mentioned above, the impact of a space project on the economy as a whole is occasionally on a-priori consideration. Econometric studies that demonstrate a multiplier effect in stimulation of the economy by space expenditures are sometimes presented in defense of the space effort in general, but rarely provide insight into the value of specific projects.

If future national space projects such as the Space Station are to be evaluated according to their economic benefits or commercial potential, the government must resolve several key problems. As was illustrated in Figure 4-2, a primary concern is the impact of this change in emphasis on Space Station design strategy. To the extent that demands for economic benefits diverge from more traditional requirements, the government will need to revise its evaluation criteria and perhaps change its expectations regarding costs, social benefits, and user accommodations. If, for example, the space-based OTV function were developed early for its economic and commercial potential, the resulting Space Station program would probably have a higher cost, a more narrow range of social benefits (although their magnitude could be great), and would support OTV users above all others. Hence an emphasis on economic return could be somewhat inconsistent with NASA's desire for a low-cost, multipurpose space facility.

A second difficulty alluded to earlier is that the government cannot realize an economic return on its Space Station, complicating the quest for economic benefits. When these benefits take the form of cost savings on future civil operations, the government can accrue a direct economic advantage. But cost savings and performance advances that represent profit potential do not typically drive government projects. If an OTV, for example, can provide a launch service for $10 million, and, has a market value of $100 million, this represents less of an incentive (to develop an OTV) for the government than for an entrepreneur entitled to profit from such a venture. To convert this profit potential into support for a Space Station program, the government needs to develop practical and legal means of transforming latent private sector interest into active industry involvement.

This leads to a third problem, because the government, as a nonprofit institution, lacks the expertise of the private sector in developing commercial opportunities an generating economic returns. The drawbacks of an economic-return/commercial-oriented Space Station program would be amplified by the government's inability to escape the bureaucratic constraints of the public sector. In personnel management, contracting, and marketing, the government has to abide by rules of practice that were established for protection of the public interest and not profit maximization. Significant changes in the way the government does business may be required if economic return becomes a major objective of a national Space Station program.

4.2.2 INDUSTRY (PRIVATE-SECTOR) REQUIREMENTS. Just as the government is constrained by its orientation as a public institution, private industry is limited by its particular requirements in its ability to support Space Station development. A Space Station program, even if aimed primarily at generating economic returns and commercial interest, would represent a very challenging business opportunity. Despite its promise of significant economic benefits, the Space Station presents investment problems of special concern, based on nearly every standard criterion used by industry to evaluate potential projects. If its Space Station program is to succeed in attracting and maintaining private-sector interest and support, NASA must understand and address these business considerations.

In evaluating any business opportunity, the bottom line, of course, is profitability. But profit encompasses a fairly wide spectrum of investment considerations, such as the seven key ones listed in Table 4-1. Private sector requirements for participation in a Space Station venture would be analyzed in terms of these criteria, since any potential commercial Space Station user or provider would conduct a business opportunity assessment based on these parameters.

The first two categories listed in Table 4-1, investment level and investment horizon, refer to the size and duration of the capital outlay required for entry into a business venture. The higher the investment level, the greater the cost to investors of participation; and the greater the investment horizon, the longer the investors must wait to recoup their investment. This latter function, investment horizon (or payback period) is important because of the time-value of money, which is measured in terms of present value. The further into the future any income stream is realized, the lower its present value due to the impact of interest rates. The present value (PV) of an income stream is calculated as

$$PV = \sum_{i=0}^{n} \frac{\chi_i}{(1+r)^n}$$

where χ_i is the amount of money received in year n, the number of years from the present in which the income is earned, and r is the prevailing interest rate between the present and year n. In recent years, the present value has been a particularly significant business consideration, due to the rise of interest rates during the 1970s. The higher the interest rate, the lower the present value of any given income stream. An income of $100 received 10 years in the future has a present value of about $60 if the interest rate is 5%, but if the interest rate is 10%, the present value drops under $40.

Table 4-1. Primary Commercial Investment Considerations

Investment

a. Investment level
b. Investment horizon
c. Investment recovery

Risk

a. Technical risk
b. Market rish
c. Financial risk
d. Institutional risk

Investment level and investment horizon are especially important to consider in evaluating Space Station commercial opportunities, since such a program would entail unusually severe requirements in both areas. As detailed in Section 3, the total investment requirement for establishment of a manned Space Station is in the billions of dollars, and would require as many as 10 years for completion. By contrast, the typical venture capital investment is $1 to $2 million, with an investment horizon of three to five years.[1]

The third business consideration listed in Table 4-1, investment recovery, refers to the revenue-generating potential of an investment. In this regard, the Space Station fares favorably, since the potential economic benefits of a Space Station, as described in Section 2 of the volume, are indeed considerable. These potential benefits are sufficiently impressive that they might outweigh the prohibitive investment level and payback period factors, except for the existence of substantial risk in such a venture. With regard to the four types of risk listed in Table 4-1: technical, market, financial, and institutional risk, the Space Station poses significant barriers to private investment.

Technical risk is the risk involved in creating or providing a new or untried good or service. Technical risk is characterized by the fundamental question, "Will it work?", and in the case of high technology projects such as the Space Station, this question can be pervasive. Although NASA's Skylab program provided a great deal of basic knowledge and essentially proved that a Space Station is technologically feasible, a new Space Station program would raise a completely new set of technical uncertainties. This is particularly true in the area of commercial utilization, where dependence on advanced technologies (such as the space-based OTV) would be heavy.

Market risk refers to the uncertainties involved in selling a product or service, and is the demand-side counterpart to supply-side technical risk. Market risk is based on such factors as price sensitivities, product distribution, competition, and advertising, and these conditions are usually measured by some sort of market analysis prior to any major investment. The Study of Space Station Needs, Attributes, and Architectural Options is in part a Space Station market analysis, and has revealed a great deal of market risk associated with such a venture. Since most organizations do not plan more than four or five years ahead, at least not to any great detail, it is exceedingly difficult to predict user demand for a Space Station that will not be operational for 10 years or more. This problem is intensified by the fact that Space Station services and products have inherently limited market appeal, due to their probable high cost and uncertainties regarding their availability. These conclusions were verified by industry responses to GDC's "Space Station User Brochure."

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[1]Simon, M.C., "Private Financing and Operation of a Space Station: Investment Requirements, Risk, Government Support and Other Primary Business and Management Considerations", NASA CR-169357, September 1982.

Market risk is particularly significant in the area of materials processing in space (MPS). Despite the long-term potential of MPS, there is a tremendous problem involved in interesting potential customers in a technology that remains in an infant state of development, whose benefits from a Space Station are uncertain, and whose products must have values on the order of $10,000 to $100,000 per pound in order to be cost effective. It is largely due to the impact of market risk that the launch of communications satellites via space-based OTV, and not MPS, appears the most promising commercial use of a Space Station. Despite its prohibitive investment requirements and technical risk, the OTV addresses the only proven, mature market for space utilization: the communications industry.

Financial risk pertains to investment level and payback period, and increases directly with the magnitude of these factors. The large up-front investment that would be required before any Space Station operations could be initiated poses a significant financial risk; in general, the larger the commitment of resources prior to revenue generation, the greater the financial risk. Many business ventures permit a gradual buildup of investment as sales and revenue increase, but the Space Station does not appear likely to offer an opportunity to "boot-strap" operations in this manner. Again, this is particularly evident in Space Station commercial uses. The OTV would require a multibillion dollar investment in launch vehicles, support facilities, and technology development for facilities and operations, before a single dollar in launch service revenue could be generated.

Institutional risk encompasses a broad variety of uncertainties regarding organizational and logistical factors, and is of particular concern in a Space Station program because of the involvement of government. Considerations that fall under the categorization of institutional risk include availability of Shuttle flights, Shuttle costs, government support, military requirements, taxes, economic conditions such as inflation and interest rates, and legal rulings. In addition to being an important and complex factor, institutional risk is significant in that the government has considerable power to influence its impact on commercial opportunities. NASA's joint-endeavor program, which offers guaranteed Shuttle flights and other services to companies that are willing to explore new markets for space products, is one means the government has available for reducing institutional risk. Other more general government policies and actions, such as research and development tax credits, environmental and safety regulations, and international agreements, can play a significant role in reducing the institutional risk of a Space Station venture to acceptable levels.

Despite its particularly important role in influencing institutional risk, the government must be aware of all of these investment and risk considerations if it is to successfully involve the private sector in the Space Station program. As will be demonstrated in the following sections, partnership between the government and industry can be effective in addressing nearly all of these business factors, but only if the government develops a Space Station program with these matters under consideration. Similarly, the government must bear in mind its mandate to serve the public interest, and ensure that its efforts to generate commercial interest in the Space Station do not compromise its own requirements.

4.3 OPTIONS FOR GOVERNMENT-INDUSTRY PARTNERSHIP

For the government, the institutional challenge of developing a Space Station program that meets both public and private requirements is nearly as great as the technological problems that must be overcome. Government attempts at encouraging private sector involvement in large projects has historically had mixed results, and raises basic questions about the government's role in the economy. The Space Station cannot be properly defined, without determining the rights and responsibilities of the private and public sector participants in such a program.

4.3.1 THE SPACE STATION AS A SEMIPRIVATE GOOD. The easiest way to resolve the issue of private versus public participation in a Space Station venture would probably be to build the Space Station much as previous major NASA programs have been implemented, i.e., as a public good where the private sector role is limited to that of contractor to the government. In this simplest of scenarios, the government assumes all risks inherent in such an enterprise, with all benefits of the program treated as public.

Although this option remains attractive for its simplicity, it does not address the major issue facing NASA today: that the government has been reluctant to foot the entire bill for a Space Station, at least up until the present time. With strong national sentiment for limiting the government's role in the economy, and for deriving practical benefits from those programs the government is involved in, it appears that industry needs to assume a more active role in Space Station development if such a program is to be initiated. Private-sector involvement is seen to offer several advantages: it reduces the government's financial burden, ensures efficiency usually associated with private ventures, increases the likelihood of achieving a higher market sensitivity in Space Station services, and gives industry a greater incentive to develop a system whose benefits will be real and lasting. Although these ideals may seem optimistic, they are at the root of capitalist theory, which presumably is as applicable to Space Station development as to any other program for which private investment is feasible.

Is private investment in a Space Station feasible? The attractiveness of the Space Station to industry is obviously limited, or some company would already be well on its way to developing such a facility. The Space Station hence sits on a median ground - the government is not eager to sponsor it as a public good, nor is the private sector willing to develop it as a private resource. This does not necessarily indicate that the Space Station is not a worthwhile venture, but it does mean that the Space Station, to be established in the near future, will most likely be developed as a joint public-private, or semiprivate good.

Semiprivate goods are those commodities with economic and social value, but whose attractiveness to the private sector is diminished by certain barriers. Such goods are provided through government-industry partnership, with the government usually providing the initiative by offering assistance in reducing barriers to industry involvement. Through a process of "controlled privatization" the government enacts programs that address investment considerations such as those discussed in the previous section. The privatization model in Figure 4-3 gives a conceptual view of this process. Public, private, and semiprivate goods are shown as functions of their demand and investment attractiveness. Public goods have the lowest combination of demand and investment attractiveness, which is why they are not provided by private industry.

In Figure 4-3, controlled privatization is conceptually depicted as an increase in investment attractiveness brought about by government support, which encourages some level of private investment and changes a public good to a semiprivate good. This shift is shown as an upward shift of the privatization curve, rather than an outward one, since government support is not aimed at increasing demand for a good, but at influencing supply-side investment considerations. Investment level, payback period, and risk can all be addressed through various government actions, forcing the shift of public goods into the realm of semiprivate goods. The objective of the government in such cases should be to offer just enough assistance to achieve the development of the semiprivate good or service; private-sector contribution is thus maximized. This is the case in Figure 4-3, where just enough government support is offered to encourage creation of a semiprivate good, causing a shift from curve AA to curve BB. For the given demand D*, the amount of government support necessary to raise investment attractiveness from I* to I' is the minimum public commitment needed to create this semiprivate good.

Creation of semiprivate goods through government manipulation of investment conditions has many precedents in American history. Perhaps most prominent is the example of the railroad industry, where government land grants and subsidies were offered as incentives for private development of a national railway system. Such government intervention can be highly effective in encouraging private investment, as was amply demonstrated in the case of the railroads, although this support does have its perils, as evidenced by the railroad industry's continued dependence on public support. These hidden costs and dangers of government support must be addressed, as well as the effectiveness of the government in influencing investment considerations, in evaluating the government's role in Space Station commercialization.

4.3.2 <u>SPACE STATION COMMERCIALIZATION: GOVERNMENT INCENTIVES.</u> The government has a number of options that it can consider in planning for transformation of space development from a public to a semiprivate good. These various strategies influence the investment considerations detailed in the preceding section in different ways and their expected impact on these factors can provide a basis for predicting their effectiveness in encouraging private-sector involvement in a Space Station program.

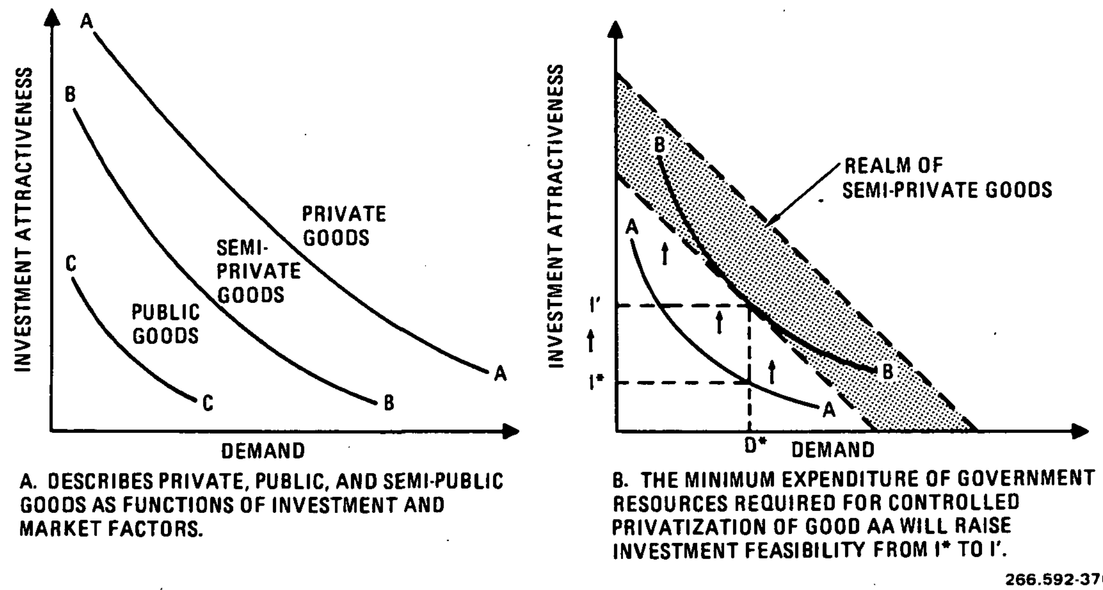

Figure 4-3. The Privatization Model

One set of options available to the government can be categorized as government incentives, where the government provides some stimulus to precipitate private investment, but with the private sector assuming primary responsibility for program management. Government incentives can be divided into three categories - financial incentives, logistical incentives, and market incentives - each having a different impact on investment considerations. Table 4-2 summarizes the general characteristics of these types of incentives and their major benefits and costs.[2]

Financial Incentives may play a key role in Space Station development, although direct cash subsidies from the government are unlikely. Research and development tax credits, however, are a more subtle and politically palatable form of financial incentives that are already being exploited in the formation of other space ventures. Proposals have also been offered for creation of a Space Bank that would make federally-subsidized low-interest loans available to investors wishing to undertake space ventures. Tax credits and, to a lesser extent, loans could be effective in reducing the financial liability and investment level requirements for Space Station investment, but would do little to mitigate the great risks that would be involved in such an enterprise.

Logistical incentives are currently employed in NASA's joint-endeavor program, where NASA-subsidized Shuttle flights are used as an incentive for companies to develop commercial space hardware. Agreements of this sort are effective in reducing institutional risk, since they demonstrate a willingness on the part of the government to work closely with private organizations toward a common goal. Logistical incentives could encourage use of Space Station facilities by private companies once a Space Station is established, but may not in themselves convince industry to invest in development of costly Space Station elements.

[2]Reprinted from Simon, M.C. "Analysis of Government's Role in Commercialization of Space Technology". c 1982 General Dynamics Corp.

Table 4-2. Government Incentives

	Benefits	Costs
Financial Government offers financial incentives to encourage investment in space; e.g., guaranteed loans, tax credits, or cash subsidies.	Highly effective in reducing investment level requirements and financial risk. Costs to government and benefits to industry are relatively simple to quantify.	Often present political problems since financial aid is highly visible and is frequently granted to private sector long before projected returns are evident.
Logistical Government offers free or reduced-cost transportation or other services as an inducement to private investment.	Allows government to use its resources to develop systems (e.g., Space Shuttle) over which the government can maintain control and that show a return on taxpayer investment.	Not as effective in stimulating private sector interest as cash assistance and dependent upon government's ability to provide services on schedule for agreed cost.
Market Government guarantees or "creates" a market by agreeing to purchase space products or services at an agreed-upon price.	Minimizes risk to government since public resources are not expended until program is completed successfully and final products or services are delivered.	Does not reduce investment level or investment horizon for private investors and usually requires long-term government commitments, often requiring special legislative action.

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Market incentives might provide a forceful supplement to logistical incentives in encouraging investment in development, as well as use, of Space Station capabilities. Market incentives were the primary force behind NASA's tracking and data relay satellite (TDRS) project with Spacecom, where NASA agreed to lease TDRS services from Spacecom in exchange for Spacecom's commitment to develop the TDRS system. Although this program does have its critics, it has been successful in creating a commercial opportunity and providing a needed resource for NASA. Market incentives are also being considered for use in NASA's joint-endeavor program. A typical Space Station application might be for NASA to agree to lease time on a laboratory module, from a private organization willing to invest in development of the lab.

4.3.3 SPACE STATION COMMERCIALIZATION: GOVERNMENT TASK SHARING. A second category of government support for commercialization, which can be characterized as government task sharing, could have applications in development of a Space Station as a semiprivate good. Government task sharing entails a greater degree of government involvement than government incentives, entrusting the public sector with the major responsibility for program management and direction. Government task sharing can similarly be segregated into three separate categories: developmental task sharing, preoperational task sharing, and elemental task sharing. Table 4-3 summarizes some of the key characteristics of these three types of government task sharing.[3]

[3]See footnote 2.

Table 4-3. Government Task Sharing

	Benefits	Costs
Developmental Government performs necessary R&D to demonstrate technical and programmatic concepts; hardware is purchased and assembled privately.	Allows agencies such as NASA to perform basic R&D functions while greatly reducing private sector financial commitments and technical risks.	Can present difficulties in distinguishing "R&D" from "production" and could result in technology development that is not optimized for private sector production and operation.
Pre-Operational Government develops and builds systems and transfers ownership and/or control to private sector after demonstrating operational capabilities.	Greatly reduces all aspects of private sector risk and investment requirements, while giving government greatest control over system development and production.	Entails greatest cost and liability to government, offering none of the advantages of private-sector development or production.
Elemental Government develops and builds core system elements and permits private companies to develop other components to add to main system.	Parallel development can offer the most equitable means of task sharing, also affords government and private sector full control over system development.	Private participants dependent upon government to provide core system elements on schedule; can also create technical and programmatic compatibility problems.

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Developmental task sharing is frequently a factor in the commercialization of high technology, where government-supported research and development is often made available to industry when business applications become feasible. An example is the nuclear power industry, where government research in nuclear energy is made available to utility companies willing to invest in the hardware necessary for commercial development of nuclear power. In the space program, technology spin-offs are another example of developmental task sharing that is not aimed at any one particular project. A more planned and specific approach to developmental task sharing could be used to encourage private investment in a Space Station, since by sponsoring research and development the government could greatly reduce the cost of building and operating Space Station facilities.

If private operation of Space Station facilities is a major goal, then preoperational task sharing could be the most effective means of achieving commercialization, although it requires the greatest commitment of public resources. Since a frequent argument against a NASA Space Station is that the government would have to make a long-term budget commitment to Space Station operations, preoperational task sharing could be attractive to the public sector despite its requirement that the government bear essentially all development and production costs. The government would retain control over the ultimate design of the facility, perhaps helping to ensure the establishment of a Space Station consistent with the public's interest. As discussed in Table 4-3, however, preoperational task sharing provides none of the benefits of private-sector development or production.

A more balanced approach to Space Station privatization might be provided by elemental task sharing, wherein the government could develop a Space Station core facility and permit private companies to attach elements dedicated to their particular commercial interests. This approach also has important drawbacks (see Table 4-3), but offers a straightforward means for dividing Space Station development, production, and operating responsibilities among government and industry program participants. Elemental task sharing also lends itself well to combinations with the government incentive approaches to controlled privatization, and could, as discussed in Section 4.4, form the centerpiece of a government-led program to address the major private-sector Space Station investment considerations.

4.4 SPACE STATION PROGRAM RECOMMENDATION

The impediments to private investment in a Space Station venture are sufficiently high that government leadership in such a program is a practical necessity. Although there are people within government who believe the Space Station program should be exclusively a public enterprise, apparently there have not been enough to get such a project approved. So, despite the obvious need for government leadership in developing a Space Station, the private sector will have to play a prominent role in such a program. This is the fundamental reason for the emphasis on economic benefits in this study volume, and for the analysis in the previous two sections of government and industry investment requirements and partnership options. These can form the basis for a programmatic strategy that combines traditional space program funding methods with a new, commercial-oriented management approach.

4.4.1 COMPARISON OF GOVERNMENT-INDUSTRY PARTNERSHIP OPTIONS. The government incentives and government task sharing options introduced in Section 4-3 each address different private investment considerations. Table 4-4 shows the relative effectiveness of these options in influencing the seven key investment criteria discussed at the beginning of this chapter. The government task sharing options have a generally higher impact on business considerations, particularly in the areas of investment level and financial risk.

Preoperational task sharing is the most effective option overall, with a high impact on five of the seven investment considerations, and is particularly effective in reducing risk. Government incentives do not have as strong an impact in general as the task sharing options, but market incentives is the only option in either category that has an appreciable impact on investment recovery or market risk. Logistical incentives is an attractive option too, because it has precedents in NASA's joint-endeavor program and a high impact on institutional risk.

Table 4-4. Impact of Government-Industry Partnership Options on Key Investment Considerations

Partnership Option \ Investment Consideration	Investment Level	Investment Horizon	Investment Recovery	Technical Risk	Market Risk	Financial Risk	Institutional Risk
Government Incentives							
Financial Incentives	High	Mod	Low	Low	Low	High	Low
Logistical Incentives	Mod	Mod	Low	Mod	Low	Mod	High
Market Incentives	Low	Low	High	Low	High	Mod	Mod
Government Task-Sharing							
Developmental Task-Sharing	High	Mod	Low	Mod	Low	High	Low
Pre-Operational Task Sharing	High	High	Low	High	Low	High	High
Elemental Task-Sharing	High	Mod	Low	Mod	Low	High	Mod

An effective government-industry Space Station program should contain elements of several of these partnership options, so all business considerations can be addressed and to take advantage of the particular benefits each option has to offer. A combination of preoperational task sharing and market incentives would have a high impact on all seven investment criteria, but preoperational task sharing entails the greatest cost to the government so its use should be moderate. Developmental and elemental task sharing could provide an equitable means of supplementing a limited use of preoperational task sharing. Logistical incentives should be utilized for the advantages listed above. The only option that should be avoided if possible is financial incentives, since it presents particularly sensitive political problems and has adequate substitutes in the other options.

4.4.2 <u>A SPACE STATION PROGRAM STRATEGY UTILIZING GOVERNMENT-INDUSTRY PARTNERSHIP OPTIONS</u>. A first step in developing a Space Station program strategy that takes full advantages of the various government-industry partnership options is to subdivide the Space Station program into separate tasks. Figure 4-4 shows the Space Station program as separated into two time phases, development and operations, and two task divisions, core and elements. The five partnership options considered are shown according to their applicability in these task divisions.

	CORE	ELEMENTS
DEVELOPMENT	DEVELOPMENTAL TASK-SHARING PRE-OPERATIONAL TASK-SHARING	ELEMENTAL TASK-SHARING
OPERATIONS	LOGISTICAL INCENTIVES MARKET INCENTIVES	

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Figure 4-4. Space Station Task Division

The Space Station core is defined as a housekeeping or utility section that provides basic resources such as power, data management, and life support to the various Space Station users. The elements are defined as the specific operational units that are dedicated to particular uses and that derive their utility services from the core. Space Station elements could include a materials processing facility, life science labs, and an OTV base. In this analysis, development is defined as all work done prior to operations, and includes initial assembly of the Space Station.

Figure 4-4 shows that the government task sharing options are more applicable to Space Station development than operations; developmental and preoperational task sharing are employed in development of the utility core, and elemental task sharing in development of the elements. In development of the core, preoperational task sharing will be moderated to the extent that private investment can be encouraged. If the government must develop and assemble the entire core, then any subsequent private-sector involvement in core operations would be indicative of preoperational task sharing. If, on the other extreme, the government needed only to perform research and development, with private purchase and assembly of the core, then the situation could be characterized as developmental task sharing. The actual situation would probably be in between these two extremes. Operation of both the core and the elements is achieved through logistical and market incentives.

In a program scenario utilizing these partnership options, the government would act quite differently than it would in pursuing a more traditional acquisition strategy. NASA would undertake two activities in parallel: development of the utility core and the development of an initial set of elements to be integrated with the core. Figure 4-5 shows this parallel activity, with NASA effectively providing seed money for development of the core and, at the same time, coordinating development of elements through joint-endeavor agreements.

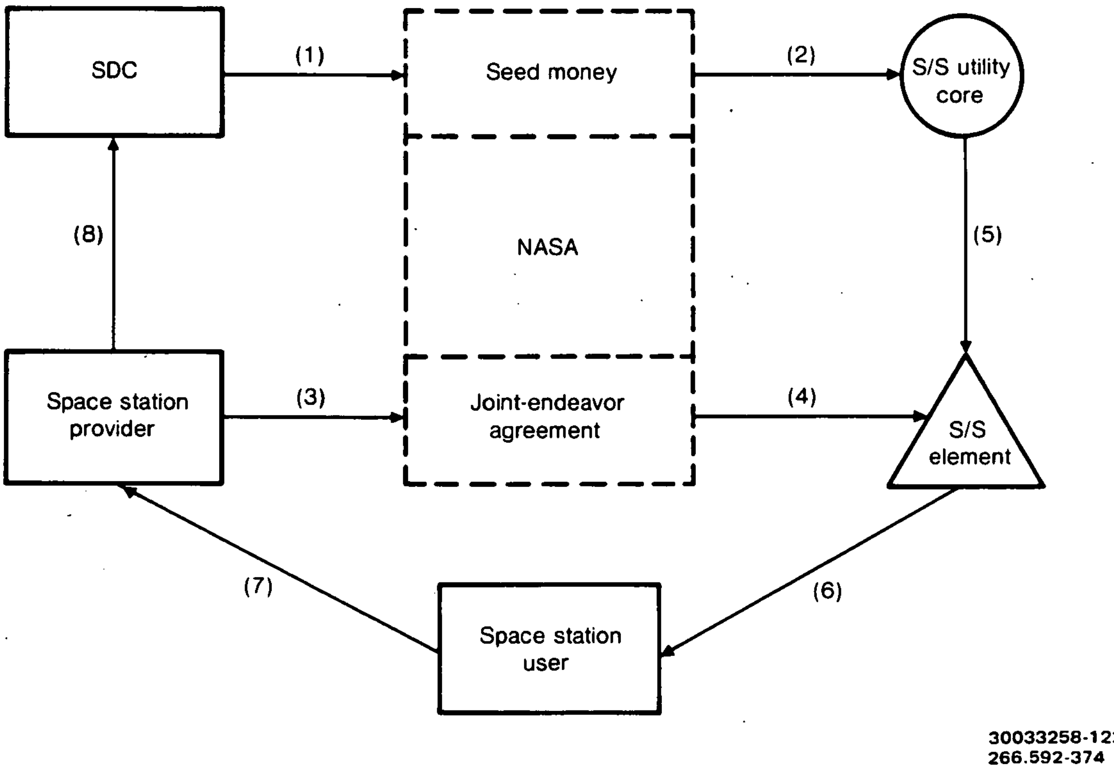

Figure 4-5. Space Station: Functional Responsibilities

A programmatic strategy of this type would achieve two major objectives: maximizing private investment in Space Station development and ensuring a Space Station that would be operated privately. The Space Station core would be operated by a Space Development Corporation (SDC), which, as illustrated in Flow (1) of Figure 4-5, would contract with NASA to operate the utility core with private funds if NASA develops the core. NASA could develop the core (Flow (2)) through more-or-less conventional means, and the SDC would prepare for operating the core once established by NASA. The SDC might be a partnership of aerospace and/or investment firms, and could be established in response to a NASA invitation to operate the Space Station Core.

NASA's parallel activity, as shown in Flow (3), would be to actively solicit joint-endeavor proposals from aerospace firms interested in becoming Space Station providers. The resulting joint-endeavor agreements (JEAs) would establish a number of Space Station providers, each one responsible for developing and operating a particular element (Flow (4)), with government support furnished through the JEA. By soliciting competitive joint-endeavor proposals, NASA could ensure the greatest possible private-sector commitment to invest in development and operation of these elements. The JEAs would be characterized by the government incentives approach, with logistical and market incentives used to diminish the barriers to private investment in Space Station elements.

The SDC would furnish utility services for the Space Station elements (Flow (5)), which would be operated by the providers for Space Station users of these elements, as shown in Flow (6). The users of the elements would reimburse the providers (Flow (7)), who would in turn reimburse the SDC for utility services (Flow (8)). As a hypothetical example, Company A, a Space Station provider, might develop and operate a materials processing module, receiving joint-endeavor support from NASA in the way of free Shuttle flights and a NASA guarantee to be a customer for an agreed level of use of the facility. Company B, a Space Station user, would lease the materials processing capabilities and reimburse Company A for these services. Company A would then reimburse the SDC for the power and data management required to run the processing facility. As illustrated in Figure 4-6, the SDC might be a limited partnership involving aerospace firms, investment firms, and perhaps even some of the small emerging space commpanies that are attempting to commercialize various space systems.

As a first step in establishing this type of Space Station program, NASA would need to establish a Space Station program office capable of performing four key tasks:

a. Publicizing the various opportunities for companies to become involved in the Space Station program. This activity might include distribution of the "Invitation to Operate" for stimulating the organization of a Space Development Corporation (SDC), and distribution of a "Request for Joint-Endeavor Proposals" to companies interested in developing and operating Space Station elements.

b. Negotiating with firms for core operations and ultimate selection of a SDC to operate the core.

c. Development of the utility core, with cooperation from the SDC to the extent necessary to enable the SDC to operate the core.

d. Negotiating with firms that submit joint-endeavor proposals for development and operation of Space Station elements, and subsequent approval of joint-endeavor agreements.

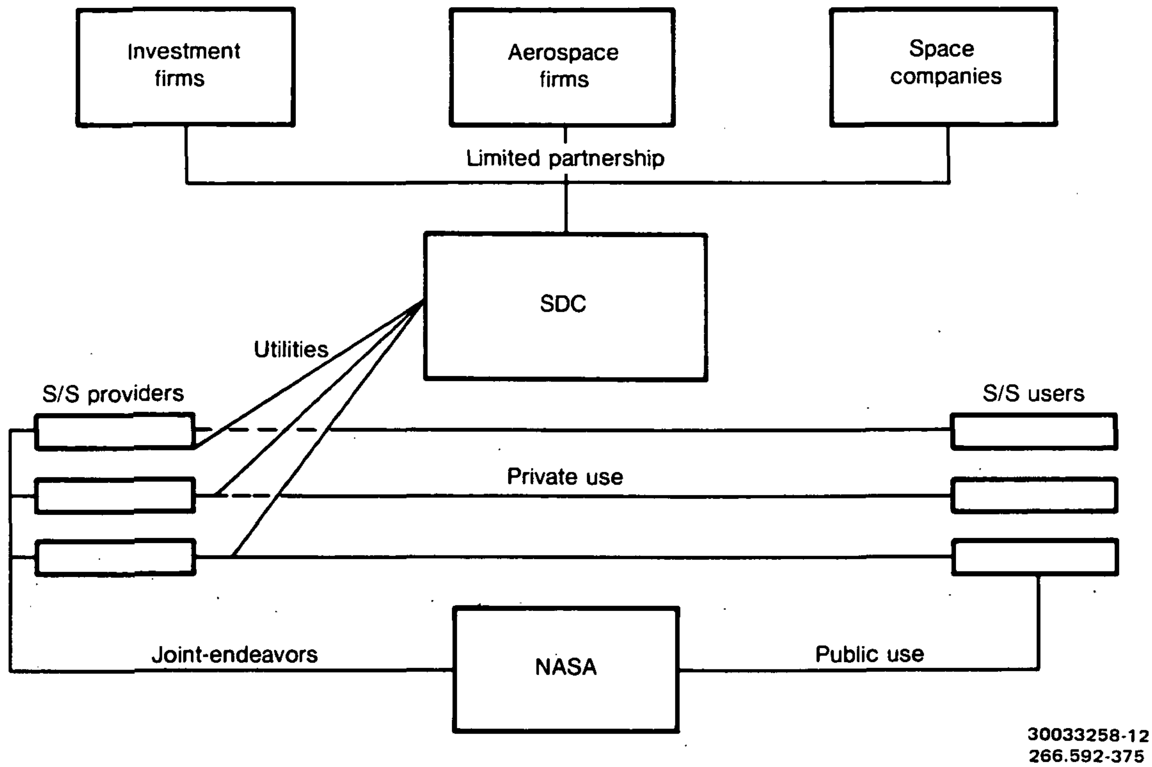

Figure 4-6. SDC Organization Option

Aerospace firms (and all other industrial companies) would have four different options for participation in this type of program:

a. As partners in the core-operating SDC.

b. As Space Station providers, developing and operating elements through joint-endeavor agreements with NASA.

c. As contractors to NASA in developing the utility core.

d. As Space Station users, leasing services from Space Station providers.

Such a program could probably be established, but many legal and institutional issues would have to be resolved, such as the antitrust implications of the SDC. It is not clear how attractive a business opportunity operation of the core and elements would be, but, by establishing this sort of program, the government would give companies an incentive to devote their own resources to evaluating the attractiveness of investing in the Space Station. Based on the potential economic benefits of the Space Station, and the possibilities for government support through a variety of governmment-industry partnership options, it seems possible that this concept or some similar programmatic strategy could succeed.

SECTION 5

CONCLUSIONS AND RECOMMENDATIONS

The principal conclusions resulting from the analysis conducted during this study are presented in Table 5-1.

Recommendations for additional near term analysis in the economic benefits and cost analysis area are listed in Table 5-2.

Table 5-1. Economic Benefits and Cost Analysis Conclusions

- The space-based OTV function offers substantial near-term economic benefits
- The research & production and the satellite servicing functions also offer some near-term economic benefits, great long-term
- The initial recommended research space station cost will be about \$5.5B at IOC & \$6.3B at full capability
- The SBOTV function incremental cost is about \$4.5B. The SBOTV & the propellant tanker will cost about \$2.7B
- The combined space station break-even in terms of economic benefits occurs about 2004
- Several options exist for creating partnership between government & industry in a space station program
- Potentially attractive business opportunities have been identified in the development of several key space station capabilities

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Table 5-2. Recommended Near-Term Economic Analyses

- Refine & continue to develop current cost/benefit projections
- Conduct space station & SBOTV operations cost & user charge analyses
- Develop cost modeling for total mission payload set (including free-flyers, etc)
- Identify & estimate funding available from other than NASA users (amount, timing, investment reimbursement, etc)

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APPENDIX I

SPACE STATION PROSPECTUS

APPENDIX I

SPACE STATION PROSPECTUS

The Space Station Prospectus was developed to show how a Space Station might be developed as a private enterprise. The prospectus is also designed to provide an effective means for NASA to market Space Station investment opportunities within the private sector. The prospectus announces a fictitious stock offering for a hypothetical corporation, "Consolidated Space Enterprises," which would form a number of subsidiary companies to develop and operate Space Station systems and elements. Although the prospectus is fictitious, it contains factual technical and economic data developed during the Space Station study, and its Business Plan and Financial Analysis show significant profit potential in such a venture.

PRELIMINARY PROSPECTUS DATED AUGUST 1, 1985

A registration statement relating to these securities may be filed with the Securities and Exchange Commission but has not yet become effective. Information contained herein is subject to completion or amendment. These securities may not be sold nor may offers to buy be accepted prior to the time the registration statement becomes effective. This prospectus shall not constitute an offer to sell or the solicitation of an offer to buy nor shall there be any sale of these securities in any State in which such offer, solicitation or sale would be unlawful prior to registration or qualification under the securities laws of any such State.

Consolidated Space Enterprises, Inc.

300,000 Shares of Common Stock

Consolidated Space Enterprises, Inc., is a new industrial corporation. The Company plans eventually to develop, build, and operate a variety of facilities and systems in space for the purpose of providing services and products on a commercial basis to private sector customers, academic institutions, and government agencies, both in the United States and abroad. Taken collectively, the facilities and systems the Company plans to operate would constitute a Space Station system. The Company believes that these facilities and systems can be developed, built, and operated in a building-block fashion, with each element implemented only when expected commercial revenues justify the investment risk. The Company plans to form a series of subsidiary companies, each with separate public offerings of shares, as each element, in the Company's opinion, becomes a reasonable commercial venture. During the first year after the effective date of this offering, the Company will conduct further studies to develop its commercial development plans and will attempt to organize as its first subsidiary the Space Power Company to provide additional electrical power to the Space Shuttle and other spacecraft by developing, building, and operating a free-flying power module in low-Earth orbit. See "The Company," "Commercial Development of Space," "The Company's Strategy for Commercial Space Development," and "Space Power Company."

NOTE: WHILE THIS PROSPECTUS IS FICTITIOUS AS TO THE EXISTENCE OF "CONSOLIDATED SPACE ENTERPRISES," THE TECHNICAL DETAILS AND THE ECONOMIC ANALYSES CONTAINED HEREIN ARE BASED ON THE FINAL REPORT ON THE STUDY OF SPACE STATION NEEDS, ATTRIBUTES, AND ARCHITECTURAL OPTIONS ISSUED BY GENERAL DYNAMICS CONVAIR DIVISION, APRIL 22, 1983.

THESE ARE SPECULATIVE SECURITIES

THESE SECURITIES HAVE NOT BEEN APPROVED OR DISAPPROVED BY THE SECURITIES AND EXCHANGE COMMISSION NOR HAS THE COMMISSION PASSED UPON THE ACCURACY OR ADEQUACY OF THIS PROSPECTUS. ANY REPRESENTATION TO THE CONTRARY IS A CRIMINAL OFFENSE.

This prospectus should be read and retained for future reference.

	Public Offering Price	Brokers' and Dealers' Commissions	Proceeds to the Company*
Per share	$10.00	$	$
Total	$3,000,000		

*Before deducting expenses payable by the Company, estimated at $

CONSOLIDATED SPACE ENTERPRISES, INC.
San Diego, California

SYNOPSIS

Shares of the Common Stock of Consolidated Space Enterprises, Inc. (the "Company") are offered to the public, directly and through selected dealers, at $10.00 per share. The minimum purchase in this offering is 100 shares. See "The Company," "Capitalization and Description of Common Stock," and "Public Offering."

Prior to the date of this offering, there has been no public market for the Company's Common Stock. After this offering, the Common Stock will be traded in the over-the-counter market. See "The Company."

The Company plans eventually to develop, build, and operate a variety of facilities and systems in space for the purpose of providing services and products on a commercial basis to private sector customers, academic institutions, and government agencies, both in the United States and abroad. The Company believes that these facilities and systems can be developed, built, and operated on a commercial basis, with each element implemented only when expected commercial revenues justify the investment risk. The Company plans to form a series of subsidiary companies, each with separate public offerings of shares, as each element becomes a reasonable commercial venture. The Company will retain a significant fraction (10 to 50%) of the shares offered at the time of formation of each subsidiary. Existing other corporations in related ground-based industries will be invited to join the Company as large shareholders at the time of formation of each subsidiary.

Although the Company has no operating history, it plans to undertake a program for commercial development of space for which the economic magnitude and technical complexity — in toto — are very large in comparison with most private enterprise undertakings. Many technological, political, and economic uncertainties lie between the Company's present activities and profitability, and an investment in the Company should be considered to be highly speculative. See "The Company," "Commercial Development of Space," and "The Company's Strategy for Commercial Space Development" under "Business Plan."

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Prepared by:
General Dynamics Convair Division
Space Station Project
Mail Zone 21-9530
P.O. Box 85357
San Diego, California 92138
April 22, 1983

THE COMPANY

Consolidated Space Enterprises, Inc. (the "Company") was incorporated in the state of Delaware on July 20, 1985.

The Company plans eventually to develop, build, and operate a variety of facilities in space for the purpose of providing services and products on a commercial basis to private sector customers, academic institutions, and government agencies, both in the United States and abroad. Taken collectively, the facilities and systems the Company plans to build and operate would constitute a Space Station system such as has been studied extensively by NASA and a number of aerospace companies under contract to NASA or to the Department of Defense during the last twenty to thirty years. (Eight parallel studies on Space Station Needs, Attributes, and Architectural Options were performed under NASA and Department of Defense sponsorship in 1982-1983 by Boeing Aerospace Company, General Dynamics Convair Division, Grumman Aerospace Corporation, Lockheed Missiles and Space Company, Martin Marietta Denver Aerospace Corporation, McDonnell Douglas Astronautics Company, Rockwell International Corporation, and TRW Inc.)

The Company believes that the facilities and systems comprising the Space Station System can be developed, built, and operated in a building-block fashion, with each element implemented only when expected commercial revenues justify the investment risk. See "The Company's Strategy for Commercial Space Development." The Company plans to form a series of subsidiary companies, each with separate public offerings of shares, as each element, in the Company's opinion, becomes a reasonable commercial venture. See "Space Station Company Profiles" under "Business Plan." The Company plans to retain a significant fraction (in the range of 10 to 50%) of the shares offered at the time of formation of each subsidiary. Existing other corporations in related ground-based industries will be invited to join the Company as large shareholders at the time of formation of each subsidiary.

Nothing will preclude other companies from entering the field of commercial operations in space in a manner directly competitive with the Company. The Company anticipates, however, that its expertise and its priority in the field will provide the competitive edge necessary for the high degree of profitability expected for the investment risks involved. In some cases, entry of other companies into a particular type of services before the Company believes those services to be economically attractive may preclude the Company for a period of time entering that marketplace. For this reason, there can be no assurance that the Company will form all of the subsidiary companies described in "Space Station Company Profiles" under "Business Plan."

If the Company succeeds in carrying through all of its commercial development program, a total investment of $5 billion to $10 billion may be required over the next ten to fifteen years. According to the General Dynamics Convair Division final report on Space Station Needs, Attributes, and Architectural Options, earnings on that investment may be $1 billion to $2 billion annually. While cooperative efforts with government agencies may reduce the total capital requirements, there is no assurance that the total capital required to carry out the Company's commercial development program can be raised or that income will ever be high enough for the Company or its subsidiaries to be profitable. Many technological, political, and economic uncertainties lie between the Company's present activities and profitability, and an investment in the Company should be considered as highly speculative.

During the first year after the effective date of this offering, the Company will conduct further studies to develop its commercial development plans and will attempt to organize as its first subsidiary the Space Power Company to provide electrical power on a commercial basis to the Space Shuttle and other spacecraft by developing building, and operating a free-flying Power Module in low-Earth orbit. See "Space Power Company" under "Space Station Company Profiles."

There has not previously been any market for the Common Stock of the Company. The Common Stock is not listed on any stock exchange and there can be no assurance of the extent or even the existence of an over-the-counter market for the Common Stock.

The Company is not now offering the Common Stock in connection with "Keogh Plans," "Individual Retirement Accounts," or any other retirement plan.

COMMERCIAL DEVELOPMENT OF SPACE

The development of commercial uses of space began in 1963 when the United States Congress chartered the Communications Satellite Corporation (COMSAT) for the purpose of creating and operating a satellite communications system on a worldwide basis. Commercial operations in space began in 1965 with the launch of COMSAT's Early Bird communications satellite into geostationary orbit (GEO).

Since then, numerous studies conducted by NASA, by aerospace companies, and by universities have shown the eventual feasibility (both technically and economically) of an enormous diversity of commercial opportunities in space. Many industrial processes can theoretically be performed more efficiently in space than on the surface of the Earth. Some of these processes have been tested experimentally in orbit aboard Skylab, during the joint American-Soviet Apollo-Soyuz flight, aboard Soviet Soyuz and Salyut flights, and aboard the Space Shuttle. A constant supply of full-strength solar energy, near-zero gravity, and very high vacuum are readily accessible in low-Earth orbit (LEO). Unobstructed view of large portions of the Earth in a very short period of time offers the opportunity for rapid and inexpensive geological prospecting, crop assessment, resource management, and environmental monitoring. Possibilities for much of this technology have already been developed by NASA in the Landsat (Earth Resources Satellite) program and by private firms specializing in the image processing and interpretation of space-based remote sensing data.

Further possibilities include the conversion of solar energy in space into forms suitable for transmission to the surface of the Earth (either by microwave or laser beams) for use on Earth as electrical power or as a source of synthetic fuels, and the eventual mining of raw materials from the Moon and the asteroids for use in space and on Earth.

The commercial development of space has been enhanced by the development and operation of the Space Shuttle, which has reduced the cost of transportation from the surface of the Earth to low-Earth orbit and has increased the size and mass of cargos which can be delivered to orbit. The development and construction of the various facilities and systems making up a Space Station is expected to enhance the possibilities for commercial operations in space still further, and it is by providing those facilities and by vigorously marketing those facilities that the Company intends to achieve a high level of profitability.

The commercial possibilities presently foreseen in space and the role that Space Station facilities would play in development of these commercial ventures are described in greater detail below.

Information Services

Information services in space comprise communications satellites, remote sensing satellites, navigation satellites, and geolocation satellites. At the present time, most communications satellites, whether operated commercially or by the military services, are placed in geostationary orbit (GEO) some 22,300 miles above the Earth's equator. At that altitude, the period of revolution about the Earth is 24 hours, the same as the period for the Earth itself to rotate about its axis, so that a satellite placed there appears to be fixed in the sky, providing a constant link between any pair of points on Earth in view of the satellite. With present day technologies for the electronic systems aboard a large communications satellite such as the INTELSAT-VI series, the communications capacity of the satellite is sufficiently large to generate revenues of up to $10 million per month. During the ten year period from 1986 through 1995, it is anticipated that the International Telecommunications Satellite Organization (INTELSAT), the International Maritime Satellite Organization (INMARSAT), and domestic U.S. telecomunications companies will place into operation new satellite capacity equivalent to 50 to 100 INTELSAT-VI spacecraft. Military communications satellites, of comparable size, may be launched in similar numbers during the same period.

Remote sensing satellites include weather satellites, both in GEO and in lower altitude orbits; military satellites in GEO to provide early warning of rocket and missile launches; military reconnanissance and ocean surveillance satellites in LEO; and Earth resources satellites such as LANDSAT in LEO. The numbers of such satellites to be launched during the next ten years will depend very strongly on the commercial viability of the Earth resources satellites, which is highly uncertain at the present time for institutional, technological, and political reasons.

Navigation satellites at the present time are operated only by the military services in high Earth orbits, but it is possible that a separate system may be developed for civilian air navigation. A total of up to 18 satellites may be launched for the military Global Positioning Satellite system by 1995.

Very large platforms placed in GEO which could interrogate small transponders aboard ground vehicles, aircraft, surface vessels, or very high value packages could locate such items almost anywhere on Earth within 300 feet. With a sufficient number of users for such a geolocation service, a modest charge for each interrogation (about $10) would make this service commercially viable. At the present time, the Company is unaware of any firm plans by any company or government agency to develop, build, and operate such satellites.

Cumulatively, revenues from information services in space are estimated to exceed $10 billion per year by 1990, rising to about $100 billion per year around the turn of the century, according to a study on space industrialization performed by Science Applications, Inc., for NASA in 1977-1978.

Space Products

A great deal of research has been conducted on the subject of materials processing in space (MPS), taking advantage of the near-zero gravity environment — occasionally coupled with the accessibility of very high vacuum and very low or very high temperatures using either shades or solar concentrators — to fabricate products or materials of very high value per pound. In order to be commercially successful, such products or materials must be either better or cheaper than Earth-made equivalents, or must be entirely novel, offering functions which cannot be achieved with Earth-based processes.

At the present time, NASA has undertaken a joint endeavor with McDonnell Douglas Astronautics Company and Johnson and Johnson, Inc. to develop equipment to provide electrophoretic separation of proprietary biological substances in a series of flights aboard the Space Shuttle. It is anticipated that a production facility which can be carried into space aboard the Space Shuttle and, perhaps, attached to a Space Station permanently will result from this program, yielding commercial quantities of several different biological and pharmaceutical substances of far greater purity than can be produced on the Earth.

Other possibilities include semiconductor materials, high grade optical glasses, very high strength fibers, high performance magnetic materials, and new ceramic materials for specialized applications on Earth.

With further maturity of the Space Shuttle system, complemented by permanent facilities in LEO for human habitation, assembly and construction of large platforms will becom feasible, platforms far larger and heavier than can be launched aboard a single Space Shuttle flight. Large platforms could provide much more versatile and capable communications systems than are presently possible, as well as new services such as geolocation.

Space Transportation

The Space Shuttle is designed to carry cargoes and people from the surface of the Earth to low-Earth orbit (up to about 500 miles altitude) and back. As discussed above, many of the most profitable Space Shuttle payloads must be placed in GEO. Thus, some kind of propulsion system is needed to transfer these payloads from LEO to higher orbits, often with a change in inclination of the plane of the orbit as well. At the present time, this transfer is accomplished with expendable systems. Significant reductions in the cost of placing satellites in GEO and other high-Earth orbits will eventually be achieved by using reusable orbital transfer vehicles (OTVs). The establishment of permanent facilities in LEO to refuel, maintain, and launch OTVs will reduce the cost of placing satellites in GEO still further.

Repair, refurbishment, and upgrading of satellites from permanent facilities in LEO is anticipated to be feasible by the early 1990s. Transportation of repair equipment (or of the satellites themselves) between such permanent facilities and the operating orbital locations of the satellites to be repaired will require use of a teleoperator maneuvering system (TMS), a self-propelled remotely controllable industrial robot, as well as OTVs.

Should the construction and placement of very large platforms in high-Earth orbit (including GEO) become economically attractive, orbital transfer vehicles (OTVs) of much larger payload capacity will be required. These may depend on continuous low thrust propulsion systems such as electric ion engines instead of chemical rocket engines, in order to reduce the quantity of propellants required to deliver a given cargo.

Other Services in Orbit

In the early stages of the commercial development of space, the principal opportunities (such as communications satellites) have been oriented to providing services to customers on the Earth. As the scale of commercial activities in space increase, however, new opportunities for providing support services to customers in space will emerge. These services will include energy supply, repair and construction services, fuel supply for space transportation, and living accommodations for workers in space.

Electrical power on board the Space Shuttle is provided by a combination of electric storage batteries and fuel cells, which produce electricity from the chemical interaction of hydrogen and oxygen to produce water. Some portion of the payload capacity of the Space Shuttle is devoted to the chemicals consumed by the fuel cells and to tanks containing those chemicals. The capacity of the Space Shuttle to accomplish any tasks on orbit which require significant levels of energy consumption is thereby limited. One or more free-flying power modules (consisting of large arrays of photovoltaic cells, storage batteries, and power conditioning equipment) permanently placed in low-Earth orbits would significantly enhance the capability of the Space Shuttle for on-orbit construction and for materials processing in space. The Space Shuttle would rendezvous with such a power module and "plug in" its electrical supply system to the power module. Such a power module could also be the initial building block and an indispensable element of a Space Station.

Assembly and construction of large satellites; final checkout of satellites in LEO before transfer to higher orbits; and repair, refurbishment, and upgrading of satellites and space vehicles in orbit offer significant potential for increasing the longevity and capabilities of space systems and thus for reducing their net cost. Such services could be provided more effectively with permanent facilities in orbit.

Transportation systems in space (e.g., OTV, TMS) require refueling in LEO to achieve the advantages of resuability. Fuel can be delivered from the surface of the Earth to LEO by dedicating space in the cargo bay of the Space Shuttle, but delivery costs could be significantly reduced by a number of alternatives. The main engines of the Space Shuttle use liquid oxygen and liquid hydrogen from the External Tank (ET). At the present time, the ET is separated from the Space Shuttle Orbiter just before the Orbiter obtains full orbital speed. The ET then falls back into the atmosphere to disintegrate over remote regions of the Indian Ocean after launch from Cape Canaveral. The ET could, however, be carried into orbit, where a substantial quantity of residual propellants (about 5 tons) could be recovered for use by orbital transportation systems. Development and construction of hardware to recover cryogenic propellants from the ET, to provide long term storage of these propellants and to refuel space vehicles should thus proceed hand-in-hand with development and construction of the OTV.

The need to have human beings in space to perform the increasingly extensive and complex activities discussed thus far is expected to increase rapidly despite advances in robotics and remotely-operated machinery. While the Space Shuttle, supplemented by a power module, provides living accommodations for small crews in space for up to 3 or 4 weeks, it would be economically inefficient to tie up the Orbiter for use in this manner. Permanent living accommodations and work bases in LEO for space workers are thus expected to become economically attractive by about 1990.

Longer Term Possibilities

The virtually continuous availability of full intensity sunlight, unattenuated by the Earth's atmosphere, in GEO, has focused considerable attention to the Solar Power Satellite (SPS) concept. Dr. Peter E. Glaser first proposed the concept in a scientific journal in 1968, and was issued a patent in December 1973. In the SPS scheme, large photovoltaic arrays or mirrors focusing sunlight into a boiler to drive a turbogenerator would produce very large quantities of electrical power which would then be converted into microwave energy or laser energy for transmission to receiver stations on the Earth. Incoming beams would then be converted back into electricity or into chemical fuels for distribution and use by conventional means. The concept was studied extensively by NASA, the Department of Energy, and a large number of aerospace contractors and university and think tank researchers. Gross revenues for such systems could reach $200 to $500 billion annually by the second or third decade of the next century.

As an alternative to bringing up all the components and the assembly equipment from Earth, Dr. Gerard K. O'Neill proposed in 1975 that SPSs be built primarily from raw materials mined on the Moon. Since the Moon's gravity is weaker than the Earth's, much less energy (and thus less cost) is needed to lift the same mass from the Moon than from the Earth. A subsequent study performed by General Dynamics Convair Division in 1978-1979 on Lunar Resources Utilization validated this basic concept, showing that more than 90% of the mass required for each SPS could be obtained from the Moon.

In 1976, Dr. Brian F. O'Leary proposed that the raw materials for building SPSs could be obtained at still lower energy cost from near-Earth asteroids. He has further proposed that strategic metals (titanium, chronium, nickel, cobalt, platinum iridium, rhodium, and palladium, to name a few) could be obtained from the asteroids in significant quantities by about the turn of the century. Other asteroidal materials (including water, carbon, hydrogen, and nitrogen) could eventually be used in large greenhouse-like structures in space to raise agricultural crops on a very large scale for delivery back to Earth.

Obtaining raw materials from non-terrestrial sources (whether from the Moon, from the asteroids, or from the moons of other planets of the solar system) would eventually permit construction of very large habitats in free space ("space colonies") for very large human populations, extending the total fabric of human civilization and commerce beyond the biosphere of the Earth and out into the solar system.

The Role of the Space Station

The Space Station has become widely regarded as the "next logical step" in America's Space Program. Establishment of a permanent manned base in low Earth orbit will complement the Space Shuttle system, and will open up a wide range of commercial and scientific opportunities. It will play a pivotal role in the commercial development of space, since it is difficult to envision a major space initiative which would not benefit substantially from the availability of a manned Space Station. The attractiveness of the Space Station as a business venture is based largely on its utility to such a broad base of potential users.

The greatest near-term Space Station business opportunity will be in the rapidly-expanding space transportation industry. A mature and growing market for the launch of payloads into high-energy orbits, i.e., beyond the range of the Shuttle Orbiter is well established. As a stag-

ing base for the transfer of payloads from the Orbiter to these higher orbits, the Space Station will revolutionize space transportation. A space-based orbital transfer vehicle (OTV), maintained and serviced at the Space Station will deliver satellites to their desired orbits at a far lower cost than any foreseeable competitor. By redesigning payloads to maximize the advantages of the OTV, a communications satellite which now costs over $100 million to launch could be launched by the Shuttle-OTV combination for as little as $10 million. Based on estimates of the future market for launch services, the OTV will have a profit potential (net economic benefit) of over $1 billion per year by the mid-1990s.

The OTV will be used primarily for the launch of commercial communciations satellites. The communications industry will also provide a market for the use of the Space Station as a test base for advanced communications technologies, which could result in the development of such products as portable "wristwatch telephones". The wristwatch telephone concept developed by the Aerospace Corporation in 1977 has a market potential which could exceed $15 billion per year, by the turn of the century, and could be operational by the early 1990s. Another major user of Space Station technology development capabilities will be U.S. government agencies which will also provide a firm market for the many technology development and scientific missions which a Space Station will accommodate.

Science and applications disciplines which will benefit from the Space Station include astrophysics, Earth and planetary observations, life sciences, and materials processing in space. The NASA market for these services can be expected to be supplemented by foreign government users, and, as Space Satation costs decline, industrial and academic researchers. Of particular interest is the Space Station's potential business in materials processing in space (MPS). Production of certain high-value products, such as pharmaceuticals and crystals, can be improved dramatically in the zero-gravity environment of space. Several companies have already surged forward in the commercialization of this infant MPS technology, including McDonnell-Douglas Astronautics Company and Johnson and Johnson who have teamed up to develop an automated space facility for commercial pharmaceutical production. If this project is successful, McDonnell-Douglas and Johnson and Johnson will be potential Space Station users as early as 1988.

Servicing and repair of satellites from the Space Station represent another promising business opportunity. Missions to service satellites which would not be cost-effective if launched via the Shuttle, could be staged from the Space Station profitably. Use of a Space Station-based teleoperator maneuvering system (TMS), a remote-controlled device for retrieving and/or servicing satellites, has a market potential of nearly half a billion dollars per year.

When Space Station operations mature (by the mid-to-late 1990s), the Space station will serve as the focal point for expansion of space industries. Lunar mining and asteroid retrieval, for provision of non-terrestrial raw materials, will be greatly facilitated by the availability of a space-based transportation system in Earth-orbit. The technology of materials processing in space developed on the Space Staton will seed the establishment of large space factories for processing of these raw materials. Advancements in the technology of large space structures, also made possible by the Space Station, will permit the assembly of space systems such as Solar Power Satellites and permanent space settlements. Eventually, many polluting industries could be removed from Earth and relocated in space. The industrial firms which participate in Space Station development will be the first to benefit from these large-scale space manunfacturing enterprises.

BUSINESS PLAN

The company believes that the facilities and systems comprising a Space Station system can be developed, built, and operated in a building-block fashion, with each element implemented only when expected commercial revenues justify the investment risk.

The company plans to form a series of subsidiary companies, each with separate public offerings of shares, as each element, in the company's opinion, becomes a reasonable commercial venture. The company has developed a Space Station development scenario which its founders believe is reasonable, based on both the technical and the economic considerations which such a project would involve.

The Company's Strategy for Commercial Space Development

The company plans to expedite the industrial development of space, and ensure its own leading role in creation of commercial opportunities in space, through a comprehensive investment plan for financing the elements of the first manned Space Station. The company will form ten subsidiary Space Station companies, each of which shall develop and market a particular set of Space Station services. The company will serve as general partner in each of the ten subsidiaries, retaining ownership of ten to fifty percent of each company's stock. The remaining shares of each company will be offered to other industrial firms and the general public. Industrial firms which have production or service capabilities compatible with Space Station development requirements can be expected to invest in the company or companies whose Space Station activities correspond to these interests. Utility firms, for example, may have a particular interest in investing in Space Power Company, which will develop and operate the Space Station power system.

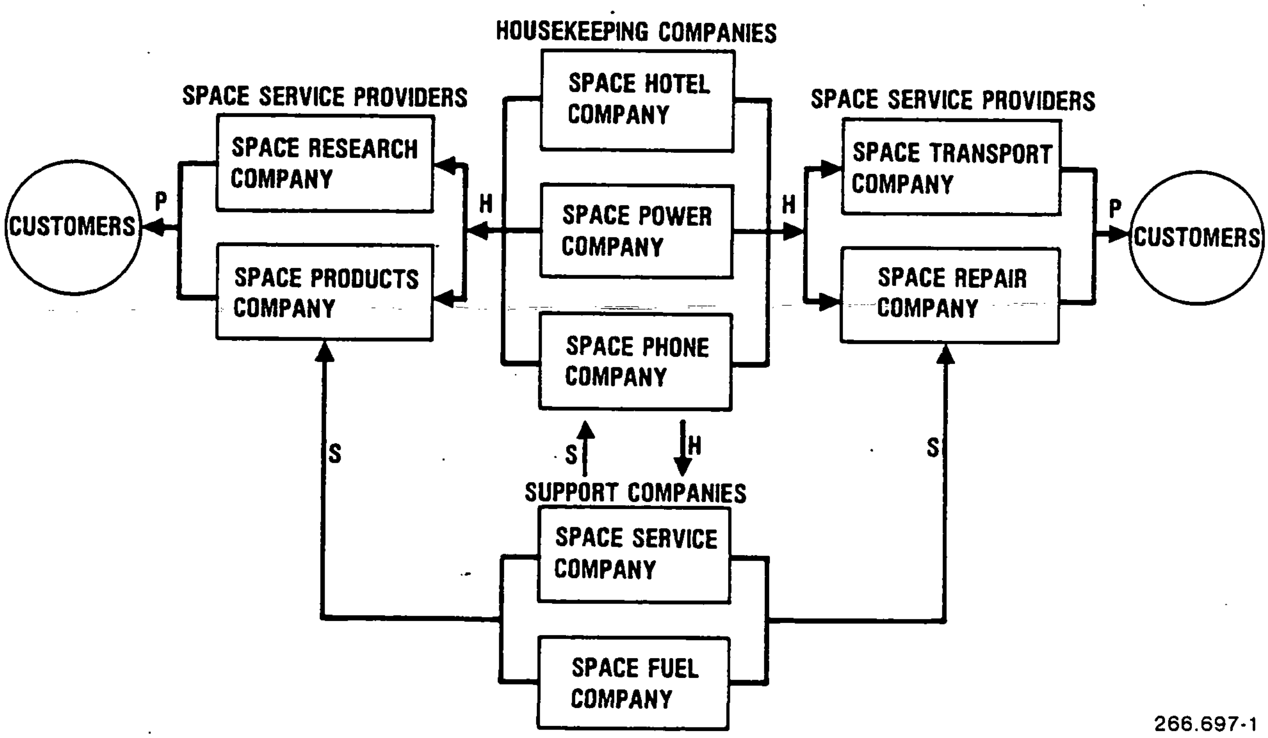
The ten Space Station companies are as follows:

1. Space Transport Company
2. Space Repair Company
3. Space Research Company
4. Space Products Company
5. Space Service Company
6. Space Fuel Company
7. Space Hotel Company
8. Space Power Company
9. Space Phone Company
10. Space Systems Company

The first four companies will develop and provide services directly to Space Station customers. Space Transport Company will develop and operate the space-based OTV; Space Repair Company will service satellites; Space Research Company will perform technology development, science and applications; and Space Products Company will manage space production (materials processing in space). These four companies will contract for support services from Space Service Company, which will be responsible for technical maintenance and servicing of major Space Station systems, and Space Fuel Company, which will deliver propellants to the Space Station for sale to the various Space Station companies. All of the Space Station companies will contract for the services of the three "housekeeping" companies: Space Station systems integration will be the responsibility of Space Systems Company, a special wholly-owned subsidiary of The Company.

Some of the Space Station companies, such as Space Transport Company and Space Service Company, will have strong commercial markets from the outset. Other companies, particularly Space Research Company and Space Phone Company, will depend to varous degrees on partnership with the United States government, which will have a continuing interest in the Space Station and may be a major customer for its services. Various options for government-industry partnership in a Space Station enterprise are discussed in the final report of General Dynamics Corporation's *Study of Space Station Needs, Attributes and Architectural Options*, presented to NASA in 1983. This document is also the source of the economic and cost data contained in this prospectus.

The interaction of the Space Station companies is illustrated in the figure below. Housekeeping services are represented by arrows labelled "H", support services by arrows labelled "S", and services to commercial and government customers by arrows labelled "P". Space Systems Company, not shown, will prevent operational conflicts among hardware owned by the various Space Station companies and charge the nine independent companies for its services.



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SPACE STATION COMPANY PROFILES

Following are business profiles of the nine independent Space Station companies. Each profile discusses the particular company's major business considerations and market prospects, and concludes with an assessment of the investment opportunity. It should be restated that the technical and economic data contained in these profiles are derived from the aforementioned General Dynamics Space Station study. The concluding Business Plan Summary provides an overall financial picture of the Space Station, and illustrates the relative attractiveness of the various ventures which the company intends to initiate.

Space Transport Company

I. Concept

Space Transport Company shall develop, construct, and operate systems for the transportation of cargo from the Space Station to final orbital destinations beyond the range of the Space Shuttle. The transportation system will consist of a fleet of chemical-propulsion orbital transfer vehicles (OTVs), which will be fully reusable and maintained at the Space Station by the Space Service Company. The initial OTV will be an unmanned vehicle capable of transporting about 11,000 pounds of payload from the low-Earth orbit Space Station to geosynchronous orbit. Advanced OTVs will transport personnel and cargo throughout the Earth-Moon system and beyond, in support of lunar and interplanetary missions.

II. Market

The initial market for OTV services will be delivery of commercial communications satellites to geosynchronous orbit (GEO); as many as thirty such satellites may be launched each year during the 1990s. Whereas current expendable launch systems cost from $30 million to $150 million for delivery of a single communications satellite to GEO, the OTV should provide launch services at a total cost of $10-20 million per satellite launched. The market for Space Transport Company is well established; estimates of launch service revenue during the 1990s range from $10 billion to $20 billion. The commercial satellite market will be augmented by demands for launch of science and national security payloads, and the ultimate development of deep-space operations such as lunar mining and asteroid retrieval.

III. Investment Requirements

Development of a fleet of space-based OTVs is estimated to cost about $1.5 billion. Development of OTV support facilities will cost considerably more, but most of these costs should be borne by the Space Fuel Company and the Space Service Company. OTV operating costs are estimated at about $30-40 million per mission, depending on the payload and destination, much of which consists of the costs of OTV propellants to be purchased from Space Fuel Company.

IV. Business Arrangements

The activities of Space Transport Company will include development and testing of the space-based OTV, in coordination with the other companies whose support services will be required. OTV operations will require payload transfer from the Space Shuttle to the OTV, ground and space monitoring of each OTV flight, checkout of the OTV after every mission, with periodic repairs and maintenance of the OTVs between missions. Space Transport Company will carry out launch service agreements directly with its government and industry customers, and will itself be a customer for several Space Station services. Space Transport Company will need to purchase OTV propellants from Space Fuel Company, OTV repair services from Space Service Company, living accommodations for personnel from Space Hotel Company, and communications from Space Phone Company.

V. Business Assessment

Space Transport Company represents one of the most attractive investment opportunities within the Space Station system. The OTV economic advantage over current launch systems is substantial, and the market for launch services is large, firm, and growing. The economic benefit the OTV over alternative systems is estimated at over $1 billion annually, and Space Transport Company's share of this profit potential should be sufficient to provide a strong return on the investment in development of the OTV capability. Owing to the overall significance of the OTV function to the Space Station program, significant government support for OTV development should be available, though it should not be necessary, assuming OTV-related development costs can be shared equitably among the Space Station companies involved with the OTV.

Space Repair Company

I. Concept

Space Repair company shall develop and operate the teleoperator maneuvering system (TMS), unmanned servicing module (USM), and other equipment for performing satellite servicing and other tasks related to the maintenance, repair, and upgrading of orbital assets. Whenever possible, satellite servicing missions will be unmanned and performed "in-situ" at the location of the serviced asset. Most serviced satellites will be within the operating range of the Space Station-based TMS, i.e., within 600 miles in altitude or eight degrees in orbital inclination of the Space Station. Satellites will occasionally be retrieved and brought to the Space Station for servicing, and for about ten percent of servicing missions Space Repair Company will need to coordinate with Space Transport Company for utilization of the space-based OTV.

II. Market

Satellite servicing should develop into a $350 million per year market by the mid-1990s, requiring an average of about twenty servicing missions annually. Approximately one-third of these missions are expected to be for scheduled maintenance, with servicing missions for repair of unplanned malfunctions occurring about twice as frequently. Primary consumers will be science and applications customers whose satellites are expected to be more attractive for servicing than commercial satellites based on such factors as satellite value, location, and reliability. Space Repair Company will interact directly with the customer community, and will in turn contract with other Space Station companies for support of satellite servicing operations.

III. Investment Requirements

Capital investment requirements for establishment of Space Repair Company's satellite servicing capability should be approximately $200 million, with a majority of this outlay devoted to development of the TMS and USM. A small portion of the investment will be for development and production of the tools which Space Repair Company will need, and for modifications to the Space Station to permit the occasional return of satellites to the Space Station for servicing tasks which cannot be performed in-situ.

IV. Business Arrangements

Space Repair Company will contract with Space Service Company for TMS storage and assistance in TMS maintenance, and will purchase TMS propellant replenishments for its customers from Space Fuel Company. Space Repair Company will also depend on Space Phone Company, for communications support during servicing missions. Among its customers, who will primarily be science and applications customers, will be Space Research Company and Space Products Company, who may utilize Space Repair Company for the servicing of mission-peculiar equipment on space platforms and free flyers.

V. Business Assessment

Space Repair Company represents an attractive business opportunity due to its relatively modest capital investment requirements, which (at $200 million) is the lowest of the Space Sta-

tion companies. The profit potential of satellite servicing is estimated at about $240 million annually, and Space Repair Company need only realize one-sixth of this potential for it to remain a profitable venture. Space Repair Company's share of this profit, after account for fees to its contractors and economic benefits to its customers, should remain in the 30-40% range, so this venture appears to be an attractive opportunity with a relatively low level of financial risk.

Space Research Company

I. Concept

Space Research Company shall develop and operate Space Station elements for the support of technology development, science, and applications research. These elements will include laboratories such as life science modules, which will be part of the primary Space Station structure, and unmanned free flyers and platforms which will support observatories and experiments in a space environment uninfluenced by manned operations. Space Research Company will also be involved in the staging of interplanetary missions from the Space Station, and may eventually work with Space Transport Company to develop manned orbital transfer vehicles.

II. Market

Space Research Company will be involved in every discipline of space science and applications except materials processing in space, which will be handled by Space Products Company. Aside from its commercial remote sensing customers, Space Research Company's clientele will initially consist primarily of NASA and other U.S. government and foreign researchers. Space Research Company will generally not develop mission-peculiar equipment, but will instead operate generic Space Station facilities, such as experiment modules and free flyers, which will support a variety of missions. Science and applications users will lease this equipment from Space Research Company, and will have the option of using Space Research Company's trained mission specialists or providing their own crew support. As the cost of doing research in space declines, commercial utilization of Space Research Company's services and facilities should increase, but based on past experience it is a safe assumption that government and government-supported users will comprise the bulk of Space Research Company's early market.

III. Captial Investment

Capital investment in the various mission modules and platforms which will support science and applications customers could range from $1 billion to $2 billion, depending on the extent of the facilities and the accommodations on these facilities for supporting specific mission tasks. With a mission module development cost of about $350 million, and a unit cost of about $125 million per module, an initial research capability could be provided for as little as $500 million. It is anticipated, however, that the early Space Station configuration, which will emphasize science and applications, will require as many as five mission modules for science and applications, and a number of free flyers and platforms which will be monitored and serviced from the Space Station. Of particular interest is not only the size of the investment required for this level of activity, but also its timing. A good deal of the Space Station's technology development, science, and applications capabilities need to be in place by the early 1990s, so that commercial and operational missions which are dependent on technology development can commence on schedule.

IV. Business Arrangements

Owing to the magnitude and timing of its capital investment and its reliance on government-sponsored research for sales, Space Research Company will require active support from the government throughout its initial investment period and early operations. Space Research Company will be one of the most dependent of the Space Station companies on government involvement; this is to be expected because of the public nature of space science and applications research. The U.S. government and foreign governments will probably comprise over 90 percent of Space Research Company's market throughout the 1990s. Space Research Company will rely heavily upon support from the other Space Station companies, particularly Space Repair Company (for servicing of free flyers) and the housekeeping companies (for power, data management, and support of Space Research Company's crew).

V. Business Assessment

Space Research company will be a profitable venture only with government market guarantees, at a minimum, and perhaps may require support from the government in development of Space Station research facilities. Space Research Company may in fact assume the role of an operating authority, with the primary financial responsibility for development falling to the government. Survival of Space Research Company as a self-sustaining commercial entity in the long-term is possible, but will almost certainly require a great deal of government support at the outset.

Space Products Company

I. Concept

Space Products Company shall develop, construct, and operate Space Station facilities for experimental and commercial materials processing in space (MPS). These will include free flying and attached modules with production facilities (e.g., furnaces, separation apparata, etc), which benefit from the zero-gravity environment of space and the availability of manned presence on the Space Station. Space Products Company may ultimately participate in the development of large space manufacturing systems consisting of lunar and/or asteroidal mining facilities and deep-space factories capable of processing hundreds of thousands of tons of raw materials annually.

II. Market

Zero-gravity has been shown to offer advantages in the production of alloys, glasses and ceramics, electronics materials, and biological materials. Electronics materials (e.g., crystals) and biological materials (e.g., pharmaceuticals) seem to offer the greatest commercial potential, due to their high value per unit weight — some enzymes, for example, have market values in excess of $50 million per pound. Since MPS is a new technology, however, more research is needed before the real value of space processing can be fully known. It is, therefore, impossible to predict the size of Space Products Company's market, a market that may in the early years of Space Station activity include a good deal of government-sponsored research. The potential of commercial MPS seems great nonetheless; NASA is currently supporting through a Joint-Endeavor Agreement a project aimed at commercial pharmaceutical production in space by the late 1980s. The industry partners in this agreement (McDonnell-Douglas and Johnson and

Johnson) have committed tens of millions of dollars to the project already, and the process they are developing, continuous-flow electrophoresis, is aimed at producing by the early 1990s up to $6 billion worth of space-processed material annually. Estimates of the ultimate value of MPS range as high as $50 billion per year.

III. Investment Requirements

Development and construction of Space Station materials processing facilities is estimated to cost $500 million to $1 billion. If MPS technology develops sufficiently over the next 3 to 5 years, development of Space Station MPS facilities may become attractive purely on the basis of expected commercial utilization. Otherwise, government partnership with industry may provide the most practical means of developing an initial Space Station MPS capability. In this latter case, MPS would represent one of the science and applications disciplines that NASA would support as its share of Space Station development. Government assistance in developing MPS facilities, and/or government market guarantees, could supplement a maturing commercial market by reducing the investment required and the risk required for Space Products Company to establish commercial space processing operations.

IV. Business Arrangements

Space Products Company will be one of the two Space Station companies most dependent on partnership with the government, unless commercial MPS develops as an industry very rapidly over the next few years. Despite its great long-term profit potential, Space Products Company may require substantial government support in development of MPS facilities as a pre-requisite for establishing itself as the commercial operator of Space Station materials processing facilities. Like its counterpart, Space Research Company, Space Products Company may have the government as its major early customer. Like the companies servicing commercial users (Space Transport Company and Space Repair Company), Space Products Company will contract with Space Station housekeeping companies for utility services, with particular dependence on Space Power Company, since MPS is very power-consuming.

V. Business Assessment

Space Products Company will have great long-term growth potential; but unless commercial MPS develops rapidly during the mid-1980s, it will be dependent on partnership with the government in order for its development of any early MPS capability on Space Station to be financially attractive. The alternative is for Space Products Company to enter the market at a later date, relegating early MPS activities to Space Research Company as one of its government-supported science and applications activities. The long-term profit potential of Space Products company, however, as a possible leader in the establishment of large-scale space manufacturing is tremendous.

Space Service Company

I. Concept

Space Service Company shall develop and operate facilities for maintenance and servicing of major Space Station systems and shall maintain a service crew on board the Space Station whose time will be leased by Space Service Company for a broad variety of service-related

tasks. Primary responsibilities of Space Service Company will include development and operation of maintenance and servicing facilities for orbital transfer vehicles (OTVs) and the teleoperator maneuvering system (TMS), and periodic technical support for servicing of the Space Station power, data management, and life support systems.

II. Market

As its primary responsibility will be to maintain and service the fleet of reusable OTVs, the market for Space Service Company will be governed chiefly by the demand for geosynchronous placement of communications and other payloads. Its share of the $1 billion per year profit potential of the OTV will be supplemented by income from maintenance of the TMS, and support to other Space Station companies in servicing the critical systems that provide Space Station utilities. Space Service Company will probably maintain the largest contingent of permanent Space Station crew members (two to four) whose daily tasks will ensure smooth housekeeping operations and prompt treatment of technical problems.

III. Investment Requirements

Space Service Company will develop and operate those Space Station facilities dedicated to storage and servicing of the OTVs and TMS, excluding the propellant storage and transfer system, which will be provided by Space Fuel Company. Space Service Company will also train and employ Space Station crew members who will be responsible for Space Station housekeeping (power, data management, and life support systems) and periodic assistance in maintaining Space Station transportation and servicing capabilities. Capital outlay for OTV and TMS support facilities will represent the majority of Space Service Company's investment, comprising about $900 million out of a total $1 billion capital budget.

IV. Business Arrangements

Space Service Company will have little direct contact with Space Station customers, working instead as a supplier to the housekeeping companies (Space Power, Space Phone, and Space Hotel) which will rely entirely on Space Service Company's crew for maintenance of their systems. Space Service Company shall also contract its services to most of the other Space Station companies, particularly Space Transport Company (for OTV maintenance), and Space Repair Company (TMS maintenance). Space Service Company will not purchase OTV or TMS spares, but will assist crew members from Space Transport Company and Spare Repair Company in OTV and TMS refurbishing tasks, as well as OTV and TMS operations, when necessary. Space Service Company will in turn be a consumer of services from the housekeeping companies for crew accommodations and power for its servicing equipment.

V. Business Assessment

Space Service Company's large capital investment in OTV and TMS service facilities is backed by the high profit potential of geosynchronous launch and satellite servicing missions, which should provide an income to Space Service Company in the hundreds of millions of dollars annually. Space Service Company will have the additional business base of leasing its crew members' labor to the housekeeping companies at a probable profit (above what Space Service Company will pay Space Hotel Company for their accommodations) of $10 million per man-year.

Space Fuel Company

I. Concept

Space Fuel Company shall have the specific task of developing and operating the propellant delivery, storage, and transfer systems for provision of cryogenic and hydrazine propellants to the Space Station companies which require such fuel for transportation and attitude control systems. Primary responsibilities of Space Fuel Company will be to develop and operate a tanker launch vehicle for propellant delivery to LEO, tanks and reliquefaction apparatus for propellant storage at LEO, and pumps and pipelines for propellant transfer to consumers. A tanker could be developed by reconfiguration of hardware presently used in the Space Shuttle system. If recovery of residual propellants from the Shuttle ET on regular STS missions becomes practical, Space Fuel Company will develop and operate equipment for Shuttle propellant recovery or will purchase propellant from whichever authority (e.g., NASA) undertakes such recovery operations.

II. Market

The primary market for Space Fuel Company will be the sale of OTV propellant (hydrogen-oxygen) to Space Transport Company for OTV fuel, which should provide a revenue base of $500 million on sales of about 500,000 pounds of fuel annually. Sale of hydrazine fuel to Space Repair Company (for TMS fuel), to Space Research Company and Space Products Company (for space platform control), and to Space Service Company (for Space Station control) should augment the OTV propellant market by approximately 20 percent. Space Fuel Company may also provide fuel to Space Power Company for replenishment of fuel cells used in Space Station power generation.

III. Investment Requirements

Space Fuel Company's investment in propellant delivery, storage, and transfer systems should be in the $2 billion range. Government assistance in development of the Shuttle-derived tanker (estimated development cost: $1.2 billion) could reduce this investment requirement significantly. One option for government partnership in this activity is for NASA to not only develop but also to operate the tanker, selling its propellants to Space Fuel Company, whose primary responsibility in this case would be storage and distribution of propellants. Space Fuel Company might ulimately team up with Space Products Company to establish space processing facilities for extraction of propellants from nonterrrestrial (e.g., lunar) materials.

IV. Business Arrangements

Space Fuel Company shall operate primarily as a supplier to those Space Station companies, most notably Space Transport Company, which require on-orbit propellant. Its only direct contact with users will be in the provision of hydrazine fuel for replenishment of reaction control systems on serviced satellites, although this fuel could be provided to users through Space Repair Company. Space Fuel Company will capture a share of the $1 billion per year OTV profit potential by selling propellant to Space Transport Company at a high profit rate. Although the $1 billion OTV benefit is based on a propellant price of $500 per pound, the economic advantage of the OTV would be reduced by only about 20 percent if the propellant price were to rise to $1000 per pound. At this price, Space Fuel Company could thus be profitable without destroying the profitability of Space Transport Company.

V. Business Assessment

With propellant sales to Space Transport Company (for OTV use) at $1000 per pound, and to Space Repair Company (for the TMS) at $500 per pound, Space Fuel Company would earn annual profits of $400 million, a sound return on its investment even though its expected development costs are the highest of the Space Station companies. With revenue from other sales and the possibility of government partnership in development of propellant delivery systems, Space Fuel Company could generate even greater profits, or alternatively, sell fuel at a lower price. Development of a system for recovery of residual propellants from Shuttle ET during STS missions could also enhance Space Fuel Company's business prospects. Space Fuel Company, however, would not seem to be dependent on such favorable technical or programmatic developments, since the market should bear a propellant price sufficient for investment recovery and a substantial rate of return.

Space Hotel Company

I. Concept

Space Hotel Company shall develop and operate systems and elements for the support and comfort of Space Station crew members. These will include primarily habitat modules and their interior furnishings, and the Space Station life support system which will provide for the physiological needs of Space Station residents. The initial life support system will depend on frequent (about 90-day) Shuttle resupply missions for replenishment of crew consumables, such as food, water, and oxygen, but may eventually evolve into a partially or fully closed-loop environmental control/life support system (CELSS) capable of supporting life on board the Space Station with much larger resupply intervals.

II. Market

Space Hotel Company will provide its services for all temporary and permanent inhabitants of the Space Station and will most likely charge one basic hotel fee on a per-person basis. The Space Station initially will have a crew of at least four to eight people and is expected to expand to a crew of twelve or more by the end of the 1990s. It is expected that all of the Space Station companies, with the exception of the three housekeeping companies, will have at least one full-time crew member on the Space Station with certain companies, such as Space Service Company and Space Research Company, having two or three full-time residents. Space Hotel Company may have one full-time resident, whose major responsibilities would be the preparation of meals and housecleaning. Alternatively, Space Service Company personnel may be hired for maintenance of habitat modules and life support.

III. Capital Investment

Development of a Space Station habitat module would require an estimated $600 million investment, with an additional production cost of about $125 million per module. An initial open-loop life support system would be included in this cost, but would entail operating costs of $200 to $300 million annually. The predominant component of these operating costs would be transportation of consumables to the Space Station, giving a substantial economic incentive for development of a closed-loop life support system for reduction of resupply requirements. Such a system would cost about $400 million to develop and install, but would

eventually save up to $350 million per year in resupply costs. Investment requirements for Space Hotel Company could be strongly influenced by government regulations and safety requirements pertaining to man-rated (habitable) space systems, so Space Hotel Company would need to work closely with NASA toward mutually acceptable cost/safety requirement tradeoffs.

IV. Business Arrangements

Space Hotel Company will probably have the simplest business arrangement of the ten Space Station companies, renting its "room and board" to each of the Space Station companies with crew members and to customers who send people to work on the Station. Government agencies may frequently send mission specialists to work with Space Research Company on science and applications projects; Space Hotel Company might offer "guest rates" for those who remain on board for relatively short periods. Otherwise, Space Hotel Company can charge a flat monthly or annual rate to the Space Station companies and customers who maintain crew personnel in orbit. Rent for one person would probably be in the range of $2 to $4 million per month. Space Hotel Company may contract with Space Service Company for maintenance of its habitats and life support system (dependent on whether Space Hotel Company maintains its own crew) and will buy power and data management services from the other two housekeeping companies.

V. Business Assessment

If Space Hotel Company can charge each of its customers $2 to $4 million per month for rent, it can probably earn a good return on its investment and exist as a self-sustaining commercial entity. If the market will not bear a rental price this high, Space Hotel Company may need to engage in partnership with the government to reduce investment requirements. Based on the potential economic value of such operations as OTV launch services and satellite servicing, Space Hotel Company should be able to obtain rental fees considerably higher than this range at least for crew members engaged in these activities. Crew costs for other missions will probably not be a major factor, so business prospects for Space Hotel Company presently seem good.

Space Power Company

I. Concept

Space Power Company shall develop, construct, and operate systems for the provision of power to all orbiting assets which require such power to fulfill their mission tasks. Primary power systems will consist of solar cell arrays, with concentrators to reduce the solar cell area required. Fuel cells, batteries, or flywheels may be used for backup power and energy storage. Ultimately, nuclear power systems may be required for certain mission requirements.

II. Market

Initial Space Station power requirements during the early 1990s suggest the need for a 20-25 kW power system, increasing to a 100-150 kW capability by the end of the decade. The two primary users of on-orbit power will be materials processing in space (MPS) and the closed-cyle environmental control/life-support system (CELSS), both of which can be expected to

evolve to full capability during the mid-to-late 1990s. MPS and CELSS are attractive market candidates; MPS is expected to develop into a multi-billion dollar industry, and CELSS will represent a cost improvement over open-loop life-support systems of over $300 million annually.

Business opportunities prior to construction of a Space Station include development of a 10-25 kW power extension system for enhancement of Space Shuttle capabilities and provision of power for unmanned "free flyers." Both markets could develop by the late 1980s. Long-term market possibilities include development of megawatt-range power systems for large-scale space processing and nuclear power plants for lunar mining operations, and gigawatt-scale solar power satellites for delivery of energy to Earth. Early versions of such advanced systems may be required within 20 to 25 years.

III. Investment Requirements

Development costs of a power extension system for Space Shuttle are estimated at about $100 million, with an additional $200 million investment required for expansion to meet Space Station power requirements. Operations costs are estimated at $10 million per year. Long-term power system developments represent costs in the multi-billion dollar range, with potential revenues of similar magnitude.

IV. Business Arrangements

Space Power Company will operate fairly autonomously with respect to the other Space Station companies and will sell power to virtually all of the other companies just as utility companies sell power to industrial firms on Earth. Primary consumers of Space Station power will be Space Products Company, which will require power in the 20-40 kW range for MPS, and Space Hotel Company, which will operate the habitat life support systems. Space Shuttle users may provide an early market for Space Power Company services, and Earth-based utility companies may eventually purchase power transmitted from space by satellite power systems operated by Space Power Company. Periodic maintenance of the power system on the Space Station may require occasional servicing from Space Service Company.

V. Business Assessment

Average power consumption among Space Station users during the 1990s should total about 1 million kilowatt-hours per year. By charging a utility rate of $100/kW-hr, Space Power Company should be able to cover operating expenses (which should be relatively small) and earn a good return on its capital investment in the Space Station power system. Space Power Company's position will be enhanced by the reliance of all Space Station companies on its power for servicing their customers and by Space Power Company's relative independence from the other companies' support services.

Space Phone Company

I. Concept

Space Phone Company shall develop and operate Space Station data management and communications systems and lease such services to the other Space Station companies. These systems will include the Space Station computer system for monitoring critical subsystems and processing of mission data and communications systems for transmission of information between Earth and the space communications network.

II. Market

Data management requirements will be driven almost entirely by the requirements of Space Research Company and Space Products Company to satisfy their science and applications customers. Astrophysics and Earth and planetary exploration will consume over 99 percent of the Space Station's information management capacity with materials processing in space representing the only other significant requirement. The commercial market for Space Phone Company services will be heavily influenced by the development of commercial remote sensing and space processing activities, a difficult market to evaluate but with substantial growth potential. Routine housekeeping data requirements will be relatively minor but will provide a steady usage in an otherwise volatile market.

III. Investment Requirements

Development of Space Station information processing and data management/communications systems will require an investment of approximately $350 million in system hardware and $100 million in software. Operations costs should be relatively low, but recovery of Space Phone Company's investment could require a considerable use fee for data management services. If commercial remote sensing develops into a strong market, it may be capable of providing most of the $50 to $100 million in annual revenue which Space Phone Company will require for investment recovery. Otherwise, Space Phone Company will probably be one of the three or four Space Station companies engaged in partnership with the government for development of Space Station facilities.

IV. Business Arrangements

As one of the three Space Station housekeeping companies, Space Phone Company will conduct most of its business as a supplier to the other Space Station companies requiring data management services. Space Phone Company will not maintain a permanent crew, contracting with Space Service Company for maintenance of its on-board computer, tracking, and communications systems. If remote sensing develops as a strong commercial industry, Space Phone Company may sell data management services directly to commercial customers but will probably provide these services through Space Research Company, which will handle a vast majority of Space Phone Company's business. Government partnership with Space Phone Company in developing these services may be desirable.

V. Business Assessment

Space Phone Company's viability as a self-sustaining commercial enterprise is largely dependent upon development of a strong remote sensing industry. Even if remote sensing does provide a firm market, however, some form of government partnership with Space Phone Company may be necessary for this housekeeping function to develop into a profitable business. Although the total capital investment required, at under half a billion dollars, is one of the smallest of any of the Space Station companies, the revenue-generating potential and market characteristics of data management services do not seem to have the payback potential to attract significant private investment without some degree of government support. If Space Phone Company can expand beyond its Space Station housekeeping function, however, then its long-term profit potential is immense. Space Phone Company would have a certain technical and competitive advantage in the development of advanced communications

systems, such as the wristwatch telephone concept described earlier, with a multi-billion dollar potential market. With possibilities such as this, Space Phone Company could in the long term become a leader in the commercial use of space.

Business Plan Summary

The table on the following page ("Space Station Financial Summary") lists the ten Space Station companies and provides rough estimates of the key investment and return factors which determine their viability. Space Systems Company data have been omitted, as this will be a special subsidiary of the Company whose major function will be to resolve technical issues among the Space Station companies rather than development of a commercial market.

This Financial Summary dramatically illustrates the impressive business potential of the Space Station enterprise. The Company's subsidiaries have a combined net income of $1.87 billion annually on sales of $3.87 billion per year. Six of the nine subsidiaries are profitable without any government support; and with rapid growth of MPS technology (whereas none was assumed), at least eight, if not all nine of the companies, could be profitable. Four of the companies yield an annual return on investment of thrity percent or greater. Altogether, $9 billion is invested in the Space Station project; and with the given assumptions, less than $2 billion would have to be contributed by the government (or $440 million annually in market guarantees) to ensure the viability of all Space Station companies.

This summary is based on mature Space Station operations for a mid-to-late 1990s timeframe. Gradual buildup of the Space Station is possible as discussed earlier. The Company intends to start up each subsidiary as its market develops. A hypothetical time-phasing of Space Station development is as follows:

1988 — Space Power Company establishes Shuttle power extension system

1990 — Space Hotel Company, Space Phone Company establish initial manned capability, Space Research Company adds first science modules

1992 — Space Repair Company initiates TMS operations, Space Service Company begins developing OTV base, Space Systems Company begins systems integration tasks

1993 — Space Transport Company begins OTV test flights, Space Fuel Company begins propellant delivery/recovery operations, Space Products Company begins space processing

1994 to 2000 — Growth of all operations

This is only an example; Space Station development could in fact proceed quite differently. Space Products Company could establish MPS operations much earlier, perhaps by developing unmanned free flyers for attachment to the Space Power Company system before the initiation of manned operations. Other variations are possible. The Company will ensure that market conditions and investor interest responsibly govern the evolution of the Space Station and the

Company's subsidiaries. The corporate officials of the Company firmly believe, however, that regardless of the development scenario, the Space Station organizational and financial situation by the end of the next decade will fulfill the expectations of this prospectus. However, the need for "general purpose" Space Station facilities not discussed in this document could add $2 billion to the total cost of the venture. Although the government would logically play a role in development of such facilities, their costs might be shared in part or in full by the Space Station companies, representing an investment requirement not included in the Financial Summary. Conversely, it should be noted that the cost data contained in this document are based on standard aerospace industry cost estimating methods. Commercial production of Space Station elements could result in substantial reductions in these costs, offsetting any additional general purpose costs and perhaps further enhancing the attractiveness and profitability of the Company's venture.

Space Station Financial Summary

							Government Requirement	
	Capital Investment ($M)	Operating Costs (Annual) ($M)	Operating Revenue (Annual) ($M)	Net Income (Annual) ($M)	Return on Investment (ROI)	ROI Shortfall	Option A: Investment ($M)	Option B: Market Guarantee ($M)
Space Transport Company	1500	750	1400	650	0.43	0	0	
Space Repair Company	200	280	350	70	0.35	—	0	0
Space Research Company	1500	100	300	200	0.13	0.07	500	100
Space Products Company	1000	100	50	−50	−0.05	0.25	1000	250
Space Service Company	1000	200	400	200	0.20	—	0	0
Space Fuel Company	2000	250	600	400	0.20	—	0	0
Space Hotel Company	1000	300	600	300	0.30	—	0	0
Space Power Company	300	10	100	90	0.30	—	0	0
Space Phone Company	500	10	20	10	0.02	0.18	450	90
Space Systems Company	—	—	—	—	—	—	—	—
Total	9000	2000	3870	1870	0.21*	—	1950	440

*Average

GOVERNMENT AND INTERNATIONAL PARTICIPATION

The Company plans, through the formation of a series of subsidiary companies, to develop, build, and operate most or all of the space systems which taken collectively would comprise a Space Station system. Many of these planned activities are in areas which have been considered to require government support or even government ownership and operation. The Company believes that most, if not all, of the elements of a Space Station system can be developed, built, and operated in the private sector by treating each element as a separate com-

mercial venture which will commence development only when, in the Company's judgment, each element becomes economically attractive.

To the extent that government participation in the development of technologies or hardware is feasible politically and fiscally, the Company will seek the active participation of agencies of the U.S. government. In certain cases in which the government appears to be a natural customer (or even the principal customer) for services which can be provided by Space Station elements, the Company and its subsidiaries will seek contractual arrangements to provide guaranteed minimum use by the government of those services just as the earliest airline companies in the United States contracted with the Post Office for airmail delivery services.

Many foreign corporations and government agencies are also expected to become customers of the Company or its subsidiaries, as similar capabilities are not expected to be available on a commercial basis from any sources outside the United States. The possible benefits to the United States' international balance of payments will provide additional justification for some degree of participation by the U.S. government in the investment and/or the operating costs of Space Station elements.

MANAGEMENT

The names and addresses of the officers and directors of the Company and their principal occupations during the past five years and certain other significant activities are given below:

Name and Address	Office Held	Principal Occupations During Past 5 Years and Certain Other Activities
Otto O. Steinbronn	Chairman	Space Station Project Manager General Dynamics Convair Division
Michael C. Simon	President	Space Systems Engineering-Economist General Dynamics Convair Division
Joseph R. Bain	Executive Vice President	Director, Strategic Planning — Space General Dynamics Convair Division
J. Peter Vajk	Senior Vice President	Senior Scientist Science Applications, Inc.

John G. Bodle	Director	Tom L. Kessler	Director
Robert E. Bradley	Director	John W. Maloney	Director
Warren G. Hardy	Director	James D. Peterson	Director
Ed J. Hujsak	Director	Gordon R. Stone	Director
Charles L. Hyde	Director	Sam L. Wagner	Director

FEDERAL TAX CONSIDERATIONS

In order to increase the potential profitability of the Company and its subsidiaries and in order to stimulate commercial exploitation of the space technologies developed by government and industry in the United States during the last three decades, the Company intends to seek legislation exempting profits on operations in space from federal corporate income taxes until 1995, after which a gradually rising portion of such profits would become liable to taxation with no special treatment after 2005. There can be no assurance that the Company will be successful in securing such favorable legislation. The effect of such legislation would be to increase the net profitability of the Company and of its subsidiaries. Such legislation would not reduce the level of investment required for each venture planned by the Company, but it may reduce the cost of capital which the Company or its subsidiaries may from time to time have to borrow.

CAPITALIZATION AND DESCRIPTION OF COMMON STOCK

The Capitalization of the Company, as of the date of this Prospectus, and as adjusted to reflect the sale of the Shares offered hereby, is as follows:

	Authorized	Outstanding	As Adjusted
Shares of Common Stock ($0.10 par value)........	5,000,000	0	300,000

The Company has authorized Common Stock consisting of 5,000,000 shares of the par value of $0.10 each, all of which are of one class and have equal rights as to voting, dividends and liquidation. All shares when issued in this offering will be fully paid and nonassessable. Shares have no pre-emptive, conversion or redemption rights and are freely transferable.

The voting rights of the shares are noncumulative, which means that the holders of more than 50 percent of the shares voting for the election of directors can elect 100 percent of the directors if they choose to do so; and in such event, the holders of the remaining less than 50 percent of the shares voting for the election of directors will not be able to elect any person or persons to the Board of Directors.

The rights of the holders of shares may not be modified by a vote of less than a majority of the shares outstanding.

CSE
PUBLIC OFFERING

Consolidated Space Enterprises, Inc., is offering 300,000 Shares of its Common Stock to the public at $10.00 per share. The minimum purchase in this offering is 100 shares. This is the first of the series of stock offerings described under "The Company's Strategy for Commercial Space Development" in the part of this Prospectus headed "Business Plan."

The Company is selling the Shares through selected broker-dealers who will receive a commission of $0.70 per share. In some states the Company is itself acting as a broker-dealer and in those states it will also sell the Shares directly. The Company is soliciting indications of interest from prospective buyers and will advise the broker-dealers thereof on the date of the offering.

No dealer, salesman, or other person has been authorized to give any information or to make any representation, other than those contained in this Prospectus; and, if given or made, such information or representation must not be relied upon as having been authorized by the Company. This Prospectus does not constitute an offer by the Company in any jurisdiction to any person to whom it is unlawful for the Company to make such offer in such jurisdiction.

The Company may file with the Securities and Exchange Commission a Registration Statement under the Investment Company Act of 1940 and the Securities Act of 1933 with respect to the Company and to the Common Stock of the Company offered hereby. This Prospectus does not contain all of the information set forth in the Registration Statement, certain parts of which are omitted in accordance with Rules and Regulations of the Commission. Additional copies of this prospectus and related information may be obtained by writing to Mr. Otto O. Steinbronn or Mr. Michael C. Simon, General Dynamics Convair Division, Space Station Project, Mail Zone 21-9530, P.O. Box 85357, San Diego, California 92138.

Until December 31, 1985, all dealers effecting transactions in the Common Stock, whether or not participating in this distribution, may be required to deliver a Prospectus. This is in addition to the obligation of dealers to deliver a Prospectus when acting as underwriters and with respect to their unsold allotments or subscriptions.